

**criteria for a recommended standard . . . .**

**OCCUPATIONAL EXPOSURE  
TO  
TRICHLOROETHYLENE**



**U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE  
Public Health Service  
National Institute for Occupational Safety and Health**

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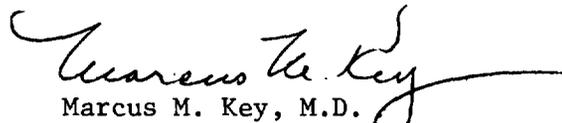
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## PREFACE

The Occupational Safety and Health Act of 1970 emphasizes the need for standards to protect the health and safety of workers exposed to an ever-increasing number of potential hazards at their workplace. To provide relevant data from which valid criteria and effective standards can be deduced, the National Institute for Occupational Safety and Health (NIOSH) has projected a formal system of research, with priorities determined on the basis of specified indices.

It is intended to present successive reports as research and epidemiologic studies are completed and sampling and analytical methods are developed. Criteria and standards will be reviewed periodically to ensure continuing protection of the worker.

I am pleased to acknowledge the contributions to this report on trichloroethylene by members of my staff and the valuable constructive comments by the Review Consultants on Trichloroethylene, by the ad hoc committees of the American Conference of Governmental Industrial Hygienists and the Society of Toxicology, by Robert B. O'Connor, M.D., NIOSH consultant in occupational medicine, and by Edwin C. Hyatt on respiratory protection. The NIOSH recommendations for standards are not necessarily a consensus of all of the consultants and professional societies that reviewed this criteria document on trichloroethylene. Lists of the NIOSH Review Committee members and of the Review Consultants appear on the following pages.

  
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CRITERIA DOCUMENT:  
RECOMMENDATIONS FOR AN OCCUPATIONAL  
EXPOSURE STANDARD FOR TRICHLOROETHYLENE

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## I. RECOMMENDATIONS FOR A TRICHLOROETHYLENE STANDARD

The National Institute for Occupational Safety and Health (NIOSH) recommends that employee exposure to trichloroethylene in the workplace be controlled by adherence to the following sections. The standard is designed to protect the health and safety of workers for an 8-hour day, 40-hour week over a working lifetime. Compliance with the standard should therefore prevent adverse effects of trichloroethylene on the health and safety of workers. Occupational exposure to trichloroethylene is defined as exposure to half of the time-weighted average limit of trichloroethylene in air or greater.

The recommended standard is measurable by techniques that are valid, reproducible, and available to industry and governmental agencies. Sufficient technology exists to permit compliance with the recommended standard. Pertinent new information will be reviewed periodically and the recommendations will be revised as necessary.

### Section 1 - Environmental (Workplace air)

#### (a) Concentration

(1) Occupational exposure to trichloroethylene shall be controlled so that workers will not be exposed to trichloroethylene at a concentration in excess of 100 ppm determined as a time-weighted average (TWA) exposure for an 8-hour workday, as measured by a minimum sampling time of 10 minutes.

(2) No worker shall be exposed to a peak concentration of trichloroethylene in excess of 150 ppm, as measured by a maximum sampling time of 10 minutes.

(b) Sampling, Calibration, and Analysis

Procedures for collection of environmental samples shall be as provided in Appendix I, or by an equivalent method. Analysis of samples shall be as provided in Appendix II, or by any method shown to be equivalent in precision, sensitivity, and accuracy to the method specified in Appendix II.

Section 2 - Medical

(a) Medical surveillance as specified in this section shall be made available to workers who are exposed to trichloroethylene.

(1) A preplacement examination shall be made available to all workers who will be exposed to trichloroethylene and within 6 months to all workers who are exposed to trichloroethylene on the effective date of this standard, and it shall consist of:

(A) A comprehensive medical history of each work applicant shall be taken. The history should be directed towards but not limited to the incidence of headaches, nausea, and dizziness; particular attention should be focused on complaints and evidence of eye, mucous membrane and skin irritation. Workers who complain of chronic eye irritation should have an ophthalmic (eye) examination.

(B) A comprehensive physical examination shall be made available, with emphasis on cardiac, pulmonary, liver, and kidney examinations.

(2) Periodic medical examinations shall be made available to workers exposed to trichloroethylene annually.

(3) Medical records shall include all required medical examinations. These records shall be available to the medical representatives of the employer, of the Secretary of Labor, of the Secretary of Health, Education, and Welfare, and, at the employee's request, to the employee's physician. These records shall be kept for at least ten years after the last occupational exposure to trichloroethylene.

Section 3 - Labeling (Posting)

(a) The following warning sign shall be affixed in a readily visible location on processing and other equipment, on trichloroethylene storage tanks or containers, and at or near entrances to areas where exposure to trichloroethylene is likely to occur:

TRICHLOROETHYLENE

WARNING! VAPOR HARMFUL

Use only with adequate ventilation.

Avoid prolonged or repeated breathing  
of vapor.

Avoid prolonged or repeated contact  
with skin.

Do not take liquid internally.

Keep trichloroethylene away from open flame and ultra-  
flame and ultraviolet radiation.

(b) If environmental levels are at or greater than the environmental standard, or if a variance permitting use of respiratory

protection has been granted, add information to the label or placard describing the location of the respirators.

Section 4 - Personal Protective Equipment and Clothing

Subsection (a) shall apply whenever a variance from the standard recommended in Section 1 is granted under provisions of the Occupational Safety and Health Act, or in the interim period during the application for a variance. When the limits of exposure prescribed in subsection (a) of Section 1 cannot be met by limiting the concentration of trichloroethylene in the work environment, an employer must establish and enforce, as provided below in subsection (a), a program of respiratory protection to provide the required protection of every worker exposed. Engineering controls shall be used wherever feasible to maintain trichloroethylene concentrations below the prescribed limits.

(a) Respiratory Protection

(1) Only appropriate respirators, as defined below, shall be provided and used when a variance which allows the use of respirators as a means of controlling exposure for routine operations has been granted or while action on application for a variance is pending.

(2) The requirements set forth in this section shall apply for nonroutine operations such as a brief exposure to concentrations in excess of the environmental standard as a result of maintenance or repair activities or in emergency situations.

(3) A respiratory protection program meeting the general requirements outlined in section 3.5 of American National Standard Practices for Respiratory Protection Z88.2-1969 shall be established and enforced by the employer. This program shall include instructions on the selection, fitting, use, testing for leakage, cleaning, and maintenance of the respiratory protective devices.

(4) For the purpose of determining the class of respirator to be used, the employer shall measure the atmospheric concentration of trichloroethylene in the workplace when the initial application for variance is made and thereafter whenever process, worksite, climate or control changes occur which are likely to affect the concentrations of airborne trichloroethylene. Only appropriate respirators as described in Table I-1 shall be used and shall be approved either under the appropriate Bureau of Mines Schedules or under 30 CFR 11 published March 25, 1972.

(5) Employees who experience breathing difficulty while wearing a respirator shall be medically examined to determine their ability to wear the respirator.

Table I-1

REQUIREMENTS FOR RESPIRATOR USAGE AT CONCENTRATIONS  
ABOVE THE STANDARD

| <u>8 Hr. TWA</u>                | <u>Respirator Type</u>   |
|---------------------------------|--|
| Less than 1000 ppm              | Chemical cartridge respirator with organic vapor cartridge(s).<br>Type C demand type supplied air respirator with half mask facepiece.   |
| Less than 5000 ppm              | Gas mask, chin type, with organic vapor canister.  |
| Less than 10000 ppm<br>or equal | Type C demand type supplied air respirator with full facepiece.  |
| Greater than 10000 ppm          | Type C continuous flow supplied air respirator.<br>Self-contained breathing apparatus in pressure-demand mode (positive pressure).<br>The self-contained breathing apparatus shall be made available and used for emergencies. |

(b) Protective Clothing

Protective clothing is normally not required for most operations using trichloroethylene. Operations where splashing, spilling, spraying, etc, or skin contact with trichloroethylene may occur

require special protective clothing. Those working in such operations shall use protective clothing made of polymer impervious to trichloroethylene such as neoprene. For any operation that necessitates skin exposure to trichloroethylene, the employee shall be provided gloves with gauntlets and bib-type apron and/or protective clothing made of a material impervious to trichloroethylene. Aprons shall be of the bib type and extend below the boot top. Shoes shall be of neoprene or covered by overshoes (disposable) of a polymer material impervious to trichloroethylene.

(c) Eye Protection

Eye protection shall be provided for any employee working in an operation that might result in liquid getting into the eye. Face shields shall be worn with respirator as described above when the operation requires such protection and a spray of trichloroethylene is possible. Suitable eye protection shall be in accordance with 29 CFR part 1910.13; this was published in the Federal Register, Volume 37, Number 202, page 22231, dated October 18, 1972.

Section 5 - Appraisal of Employees of Hazards  
from Trichloroethylene

(a) Each employee exposed to trichloroethylene and its decomposition products shall be apprised of all hazards, the consequences of overexposure, appropriate emergency procedures, proper conditions for safe use, and precautions to minimize exposure. This appraisal shall include, as a minimum, all information set forth in

Appendix III which is applicable to that specific product or material containing trichloroethylene.

(b) Each employee shall be apprised of the location of the information prescribed in paragraph (c) of this section. This information shall be kept on file and shall be readily accessible to all employees at each establishment where exposure to trichloroethylene occurs.

(c) Information as specified in Appendix III shall be recorded on U.S. Department of Labor Form OSHA-20 "Material Safety Data Sheet" or a similar form approved by the Occupational Safety and Health Administration, U.S. Department of Labor.

#### Section 6 - Work Practices

##### (a) Emergency Procedures

Emergency procedures, including those necessary for fire fighting, shall be established.

##### (b) Exhaust Systems

Engineering procedures shall be established to reduce exposure of employees to trichloroethylene vapors through implementation of adequate ventilation methods. Where a local exhaust ventilation system is used, it shall be designed and maintained to prevent the accumulation or recirculation of trichloroethylene vapor into the workroom.

##### (c) General Housekeeping

Emphasis shall be placed upon immediate cleanup of spills, periodic inspection, immediate repair of equipment and leaks, and

proper storage and disposal of materials to prevent airborne contamination and accidental skin contact with trichloroethylene.

(d) Disposal

(1) Disposal of small quantities of trichloroethylene can be accomplished by pouring the liquid onto a mixture of 10% soda ash and sand and placing the mixed material in a paper container and incinerating.

(2) Waste from cleaning contaminated with trichloroethylene should be stored in a ventilated area until ready for disposal and may be burned in an incinerator.

(e) Special Precautions

(1) Operations which generate or create high temperatures or sources of radiant energy such as those encountered in open flames, unshielded (unventilated) resistance heating, arc welding or cutting, and high intensity ultraviolet light shall not be located or conducted in areas where vapors of trichloroethylene are present.

(2) Smoking should not be permitted in areas where vapor of trichloroethylene is present.

(3) Powdered metals or turnings shall not be used or stored in any area where trichloroethylene liquid is in use or stored.

Section 7 - Sanitation Practices

Showers, hand-washing facilities, soap, and water shall be available.

## Section 8 - Monitoring and Recordkeeping Requirements

Workroom areas where it has been determined, on the basis of an industrial hygiene survey or the judgment of a compliance officer, that environmental levels of trichloroethylene are less than half of the TWA limit shall not be considered to have trichloroethylene exposure. Records of these surveys, including the basis for concluding that air levels of trichloroethylene are below half of the TWA limit, shall be kept. Requirements set forth below apply to trichloroethylene exposures.

(a) Employers shall maintain records of environmental exposures of workers to trichloroethylene based upon the sampling and recording schedule presented below.

### (1) Semiannual Requirements

Samples shall be collected in the breathing zone of representative employees at least semiannually for specific work operations. The first sampling period shall be completed within 180 days of the effective date of this standard. Sampling shall also be done whenever process, worksite climate or control changes occur which are likely to affect the concentrations of airborne trichloroethylene. Samples shall be collected and evaluated for both time-weighted average and ceiling values. The following number of breathing-zone samples shall be collected and analyzed, as a minimum, based on the number of workers exposed in any trichloroethylene exposure area:

Maximum Number of Employees

Number of Samples

Exposed at any Given Time

|          |   |
|----------|---|
| 1-20     | 5 samples or 50% of the total number of workers, whichever is greater |
| 20-100   | 10 samples plus 25% of the excess over 20 workers                     |
| over 100 | 30 samples plus 25% of the excess over 100 workers                    |

(2) Thirty-Day Requirements

The sampling regimen shall be conducted every 30 days for work areas or job activities for which the time-weighted average or ceiling concentrations are in excess of the environmental standard. Sampling, monitoring, and recordkeeping provisions of the 30-day schedule shall be required until two consecutive 30-day sampling periods have indicated that the concentrations of trichloroethylene are within the limits specified in Section 1.

(b) Records shall be maintained for ten years for all sampling schedules to include the sampling methods, analytical methods, type of respiratory protection in use (if applicable), and the concentrations of trichloroethylene in each work area. Records shall be maintained so that they can be classified by employee.

(c) Each worker shall have access to the results of samplings as they pertain to his occupational exposure.

(d) Medical records shall include information on all required medical examinations. These records shall be kept for at least ten years following the last occupational exposure to trichloroethylene.

## II. INTRODUCTION

This report presents the criteria and the recommended standard based thereon which were prepared to meet the need for preventing occupational diseases arising from exposure to trichloroethylene. The criteria document fulfills the responsibility of the Secretary of Health, Education, and Welfare, under Section 20(a)(3) of the Occupational Safety and Health Act of 1970 to "...develop criteria dealing with toxic materials and harmful physical agents and substances which will describe ... exposure levels at which no employee will suffer impaired health or functional capacities or diminished life expectancy as a result of his work experience."

The National Institute for Occupational Safety and Health (NIOSH), after a review of data and consultation with others, formalized a system for the development of criteria upon which standards can be established to protect the health of workers from exposure to hazardous chemical and physical agents.

These criteria for a standard for trichloroethylene are in a continuing series of criteria developed by NIOSH. The proposed standard applies only to the processing, manufacture, and use of trichloroethylene in products as applicable under the Occupational Safety and Health Act of 1970.

These criteria were not developed for the population-at-large and any extrapolation beyond general occupational exposures is not warranted. They are intended to assure that the standard based thereon will (1) protect against development of acute and chronic

trichloroethylene poisoning, (2) be measurable by techniques that are valid, reproducible, and available to industry and official agencies, and (3) be attainable with existing technology.

### III. BIOLOGIC EFFECTS OF EXPOSURE

#### Extent of Exposure

NIOSH has estimated that approximately 200,000 workers are exposed to trichloroethylene in the United States. Almost all of the trichloroethylene produced in the United States is used as a liquid or vapor degreasing solvent by metal fabricating industries, such as automotive, aircraft, and aerospace industries. Specific uses of trichloroethylene range in quantity and complexity from small, "bucket" operations in which the solvent is used in small quantities to clean tools or small parts to the large mass production degreasing units provided with sophisticated engineering controls.

According to Kirk and Othmer, [1] trichloroethylene was first prepared in 1864 by Fischer in the course of experiments on the reduction of hexachloroethane with hydrogen. [1] It did not receive much attention as a potential chemical product until the early 1900's at which time methods for the commercial manufacture of the material became available. Trichloroethylene was first synthesized commercially in the United States [1] in 1935 but had been manufactured in Europe [2] since 1910.

Trichloroethylene is used widely in both large and small industries. The compound is available under a variety of common and/or trade names (see Table X-1). [3,4] Because of the great number of abbreviations and common trade names for trichloroethylene and the lack of general agreement on another name or abbreviation, no abbreviation or synonym will be used in this document.

Prior to 1967, 85% of the U.S. production of trichloroethylene was prepared by the chlorination of acetylene to form 1,1,2,2-tetrachloroethane and by the dehydrochlorination of the latter to yield trichloroethylene. [5] Trichloroethylene is now produced mainly (85%) via the chlorination or oxyhydrochlorination of ethylene with the intermediate formation of ethylene dichloride which is then converted with further chlorination to trichloroethylene.

In the United States trichloroethylene is used primarily (approximately 90% of total consumption) as a solvent in vapor degreasing operations. [5] Approximately 5% of the total consumption of trichloroethylene is used as a dry-cleaning solvent for fabrics or as an extractive solvent, particularly in processes which require the selective extraction of medicines and foods. The removal of caffeine from coffee is an example. The remaining 5% finds application in a variety of operations which utilize trichloroethylene either for its solvent properties or as a chemical intermediate. These applications include the production of pesticides, waxes, gums, resins, tars, paints, varnishes, and specific chemicals such as chloroacetic acid.

Trichloroethylene is a clear, colorless, noncorrosive, nonflammable liquid with the "sweet" odor characteristic of the chlorinated hydrocarbons. Its physical properties are listed in Table X-2. [1,3,6-8]

Chemically, trichloroethylene is not dangerously reactive; however, it does slowly decompose when exposed to light and water vapor to form hydrogen chloride gas and, at elevated temperatures,

chlorine. [1,5,6] Trichloroethylene may react with strong alkalis to form dichloroacetylene (very toxic) and explosive mixtures. [9] In addition, trichloroethylene may decompose on contact with certain metals, eg, aluminum, with open flames or with ultraviolet radiation, eg, many welding operations, forming phosgene, and/or hydrogen chloride. [1,6,10] Because of the slight decomposition that is possible with the pure material, commercial grades of trichloroethylene usually contain stabilizers or inhibitors such as triethylamine, triethanolamine, epichlorohydrin or various stearates. [5,11]

Trichloroethylene vapors can easily be controlled in systems which incorporate partial enclosure, temperature control of the vapors, and/or local exhaust ventilation. However, the potential for overexposure of workers to this material exists whenever such controls are not effective and when there is (1) a need for open transfer of the liquid, (2) leakage from process equipment, or (3) maintenance or repair work on equipment or transfer systems containing trichloroethylene.

#### Early Historical Reports

In the early 1900's limited experimental studies with animals as well as evidence gained from reports of occupational overexposure in Europe had demonstrated the narcotic action of trichloroethylene. [9] Later in the 1930's it was used as a surgical anesthetic [12] and proposed for use as the basis for treatment of various nervous disorders. [13] The first reported evidence of acute overexposure to

trichloroethylene in industrial applications [2] resulted from its use as a grease solvent.

This first report of chronic poisoning from trichloroethylene in industrial situations [2] suggested that the observed effects were more likely due to impurities in the material rather than to trichloroethylene itself. From 1963 to 1967 the common manufacturing process for trichloroethylene [5] produced as an intermediate chemical 1,1,2,2-tetrachloroethane, a substance of very high toxicity. Exposure to trichloroethylene containing relatively small amounts of contaminants, such as 1,1,2,2-tetrachloroethane, could result in the development of adverse effects much different from those resulting from exposure to pure trichloroethylene. Trichloroethylene produced from acetylene accounted for 85% of total production between 1963 and 1967, 65% in 1968, 55% in 1969, and 51% in 1970-1971. In 1972 only 15% of operating capacity was based on acetylene. [5] Presently, 85% of trichloroethylene is produced from ethylene; ethylene dichloride is produced via chlorination or oxyhydrochlorination of ethylene and trichloroethylene is produced by chlorination and dehydrochlorinating the ethylene dichloride. Process control techniques available today allow manufacture of a trichloroethylene product of very high purity. This was not necessarily true of the trichloroethylene products to which early reports of overexposure refer. [9]

The studies of the metabolic formation of chloral hydrate and trichloroethanol, [14] the discovery that trichloroacetic acid was excreted in the urine of persons exposed to trichloroethylene [15] and

the subsequent adaptation of the Fujiwara reaction for the quantitative analysis of biological samples [16] brought about an era of intensive studies to develop a cause-and-effect relationship for exposures to trichloroethylene.

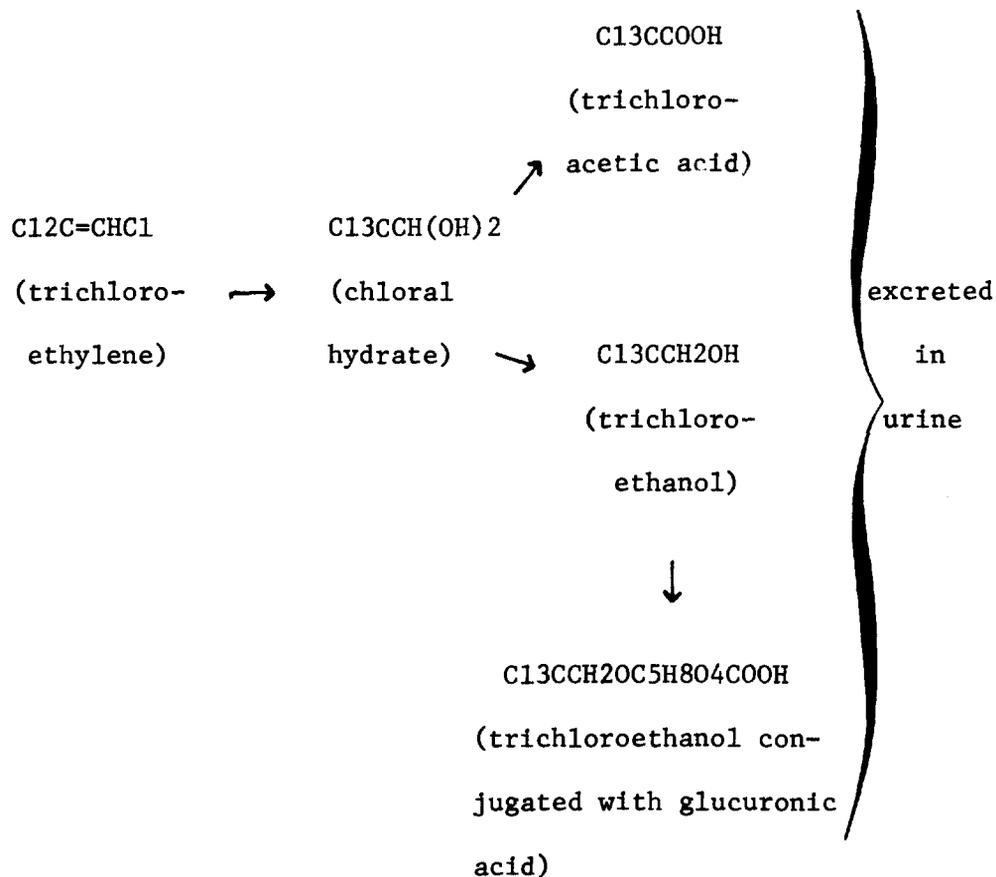
#### Effects on Humans

##### (a) Absorption, Metabolism, Distribution, and Elimination

Studies cited below indicate that trichloroethylene is absorbed rapidly by the lungs following inhalation and eliminated to only a small degree by exhalation. Barrett and Johnston [15] reported that the steam distillate of urine from human subjects exposed to trichloroethylene indicated the presence of a metabolite containing three chlorine atoms on a single carbon atom (modified Fujiwara reaction). Further investigation with dogs [16] led to the conclusion that the metabolite was trichloroacetic acid. These studies indicated that the trichloroacetic acid excreted by test animals (dogs) anesthetized with trichloroethylene amounted to 5-8 % of the absorbed trichloroethylene. Powell [17] confirmed the presence of trichloroacetic acid in urine as a metabolite of trichloroethylene in anesthetized humans. Analysis of expired air and blood samples indicated that very little unchanged trichloroethylene was present.

Butler [14] reported finding trichloroethanol, both free and conjugated with glucuronic acid, in large amounts in the urine of dogs exposed by way of inhalation to trichloroethylene. These studies indicated that trichloroethanol was produced in greater amounts than trichloroacetic acid. The author concluded that the metabolism of

trichloroethylene involves initial conversion to chloral hydrate with rapid metabolic conversion to either trichloroethanol or trichloroacetic acid.



The presence of other minor metabolites, including chloroform and monochloroacetic acid, has been reported by Soucek and Vlachova [18].

Attempts have been made by several investigators to correlate the concentrations of the various metabolites of trichloroethylene with either the degree of exposure (environmental concentrations) or the occurrence of symptoms of overexposure. [18-31]

In 1951 Ahlmark and Forssman [19] showed that the amount of trichloroacetic acid excreted in urine of workers exposed to trichloroethylene did not vary significantly with the hour of the day or amount of urine but only with the amount of exposure and the time after exposure.

Soucek and Vlachova [18] in 1960 showed that at concentrations up to 150 ppm exposed persons retained between 58 and 70% (average, 64) of the inhaled vapor. Excretion of monochloroacetic acid began within a few minutes of inhalation and was maximal at the end of exposure decreasing slowly for about 48 to 168 hours (average 112, with a biological half-life of about 15 hours). Monochloroacetic acid accounted for about 4% of the retained trichloroethylene. Excretion of trichloroacetate began shortly after the initial inhalation of trichloroethylene in a slowly rising concentration, maximal at 24 to 48 hours and diminishing thereafter as the sum of 2 exponential rates, the total excretion being equivalent to 10 to 30% (average, 19) of retained vapor. Excretion continued for 312 to 520 hours (average, 387). They noted that the daily excretion of trichloroacetic acid reached a maximum at 1:00 pm daily, irrespective of the quantity of urine excreted. Excretion of trichloroethanol began soon after the initial inhalation and rose rapidly to its maximum a few hours after the end of exposure; the total excreted was equivalent to 32 to 59% (average, 50) of the retained trichloroethylene. Excretion of trichloroethanol also appeared to fall as the sum of two exponential rates, the first phase lasting 3 or 4 days, the second lasting 7 to 9

days. Trichloroethanol excretion did not exhibit fluctuations related to time of day. In these studies, the total amount of metabolites excreted amounted to 43% to 100% (average, 73) of the trichloroethylene absorbed and the three metabolites, monochloroacetic acid, trichloroacetic acid, and trichloroethanol were found in the ratios of 1:5:12, respectively.

Bartonicek, [20] using eight resting volunteers exposed to a concentration of 1 milligram per liter (186 ppm) of trichloroethylene in five-hour periods, found that they excreted an average of 45.4% of the retained trichloroethylene as trichloroethanol and 31.9% as trichloroacetic acid, thus accounting for 77.3% of the retained trichloroethylene. Expired air analyses were performed to estimate retained trichloroethylene. Three days after exposure, the average concentration of trichloroacetic acid was 2.4 milligrams per 100 milliliters of blood plasma and 0.5 milligram per 100 milliliters red blood cells. These studies indicated that a small amount of trichloroacetic acid was excreted in sweat and in feces and, on the third day after exposure, 0.23 milligram per 100 milliliters of saliva was measured. They showed that 58% (a range of 51 to 64) of trichloroethylene inhaled at a concentration of 186 ppm was retained. Trichloroethanol excretion was maximal at the first post-exposure test (within the first 24 hours after exposure) and decreased exponentially while the rate of trichloroacetic acid excretion reached its peak 3 days after exposure and decreased more gradually for 18 days.

Bardodej and Vyskocil [21] reported that they could not correlate the levels of urinary excretion of metabolites to measured concentrations of trichloroethylene in the environment.

Kylin et al [22] showed that after exposure to 1,000 ppm loss of trichloroethylene from the lungs and the blood occurs at approximately the same pace for several hours. Frant and Westendorp [23] calculated that a person subjected to sustained exposure for several days of 100 ppm trichloroethylene in air will excrete 200 milligrams of trichloroacetate per liter of urine. Friberg et al [24] reported that 3 persons exposed for 7 hours daily for 1 week to 100 to 150 ppm trichloroethylene excreted 250 to 300 milligrams trichloroacetic acid per liter of urine during the latter days of the study.

Ogata et al [25] conducted a detailed study of trichloroethylene metabolism by exposing volunteers to trichloroethylene in 2 experiments. In the first experiment, volunteers were exposed to 170 ppm trichloroethylene for 3 hours in the morning and 4 hours in the afternoon following a one-hour break. In the second experiment, volunteers were exposed to 170 ppm trichloroethylene only for 3 hours in the morning. In both experiments the concentration of trichloroethanol in the urine reached a maximum value shortly after exposure ceased and decreased exponentially, although it was still detectable after 100 hours post-exposure. Trichloroacetic acid did not reach maximal values in the volunteers until approximately 48 hours after exposure to trichloroethylene ceased.

Ahlmark and Forssman, [19] in a study of 122 workers, related trichloroacetic acid excretion to a medical survey made independent of the biological excretory levels. Those workers with trichloroacetic acid excretion up to 20 milligrams per liter of urine reported no symptoms of trichloroethylene intoxication. Fifty percent of those excreting between 40 and 75 milligrams trichloroacetic acid per liter reported symptoms of abnormal fatigue, increased need of sleep, diffuse gastric symptoms, irritability, headache, and intolerance of alcohol. Many of the symptoms occurred among those excreting over 100 milligrams per liter and symptoms were observed in all those excreting trichloroacetic acid in excess of 300 milligrams per liter of urine. Absence from work because of illness was frequently reported for those excreting over 200 milligrams per liter of urinary trichloroacetic acid.

Andersson [26] stated in her study that no symptoms occurred in workers excreting less than 20 milligrams trichloroacetic acid per liter but most workers excreting in excess of 75 milligrams trichloroacetic acid per liter of urine exhibited symptoms of trichloroethylene intoxication. In the study reported by Grandjean et al [27] workers appeared to excrete about 8% of inhaled trichloroethylene as trichloroacetic acid in a ratio they stated as 3:1 (milligram per liter trichloroacetic acid in urine to ppm trichloroethylene in air). The ratio of trichloroacetic acid to trichloroethylene was greater (6:1) in younger persons and less (2:1) in older workers.

Ikeda et al [28] reported a deviation of the urinary excretion levels of trichloroacetic acid by 51 male workers from a linear relationship with the atmospheric concentration of trichloroethylene above 50 ppm, measured with detector tubes. Further, the trichloroacetic acid excretion showed a relative decrease with respect to the total trichloro compounds measured in the urine of workers exposed to concentrations above 70 ppm. The authors suggest that this finding may be of toxicological importance as the other metabolite (trichloroethanol) is much more neuro- and cardiotoxic than trichloroethylene.

Stewart et al [29] presented the results of a study in which attempts were made to interpret the significance of trichloroethylene in expired air collected at various times after exposure of volunteers to known concentrations of trichloroethylene. They exposed a group of seven subjects to a time-weighted average concentration of trichloroethylene of 265 ppm (range, 160 to 400 ppm) for 83 minutes. In a second experiment the time-weighted average concentration was 211 ppm (range of 172 to 332 ppm) for 190 minutes. Trichloroethylene was detectable in the expired air for more than 5 hours after exposures ceased. Results of this study, as well as those of a later investigation (1970), [30] indicated that the techniques of analyzing expired air for trichloroethylene show promise for evaluation of trichloroethylene exposures.

Kimmerle and Eben [31] exposed 3 males and 1 female, aged 20 to 30 years, to a trichloroethylene concentration of 48 plus or minus 3

ppm four hours a day on five consecutive days. No difference was found between the male and female volunteers with respect to the trichloroethylene concentration in the blood and its elimination in the expired breath. The authors reported higher concentrations of trichloroethylene in the expired breath two and three hours after exposure on the fifth day of exposure as compared with the values on the first day.

(b) Effects on the Nervous System

The first extensive medical study was that of Stuber [32] who reviewed a total of 284 cases of trichloroethylene poisoning, including 26 fatalities, which had occurred in European industrial operations. Stuber reported that the toxic action of trichloroethylene involved primarily the central nervous system although apparent effects were also observed in the gastrointestinal and circulatory systems. Adverse effects on the kidney were rare and injury to the liver was not observed in any case. The outstanding characteristics of trichloroethylene overexposure included headache, dizziness, vertigo, tremors, nausea and vomiting, sleepiness, fatigue, a feeling and appearance of light-headedness or drunkenness increasing to unconsciousness and, in some cases, to death. In addition to these consistent general symptoms, Plessner [2] noted a specific paralysis of the trigeminal nerve, an observation also reported by Persson [33]. These observations led to the early use of trichloroethylene in the treatment of trigeminal neuralgia (tic douloureux). Krantz et al [34] considered that trichloroethylene was pharmacologically active as a

depressant of all nervous tissue rather than because of a specific action on the trigeminal nerve.

Boulton and Sweet [35] reported that trigeminal palsies occurring in 24 persons after use of trichloroethylene as an anesthetic were considered to have resulted from inhalation of dichloroacetylene or phosgene or both, which the authors concluded could have resulted from the passage of the trichloroethylene through soda lime (designed to eliminate carbon dioxide from the recirculated anesthetic gas) and the subsequent reaction with the alkali to produce dichloroacetylene.

The first report of deaths resulting from acute overexposure to trichloroethylene in the United States summarized five fatal cases among industrial workers. [36] One died of apparent hepatorenal failure after accidental drinking of trichloroethylene. The remaining four workmen had been employed at degreasing operations; all had continued to work in spite of complaints of nausea, drowsiness, dizziness, and vomiting and died suddenly either at work or within a few hours after leaving the plant. The cause of death in these four cases was attributed to ventricular fibrillation. James [37] gave detailed information on a patient who had become addicted to trichloroethylene in the course of his work at an electroplating shop where trichloroethylene was used in a vapor degreaser. In addition to exhibiting symptoms characteristic of central nervous system depressant action, the man lost his sense of smell. He died suddenly some 17 hours after his last known exposure to trichloroethylene. The

cause of death was reported as cardiac arrest attributable to trichloroethylene.

Recently, Tomasini and Sartorelli [38] reported findings on a 54-year old patient following chronic and acute overexposure to trichloroethylene during operation of a dry-cleaning unit. There was a symmetric bilateral VIIIth cranial nerve deafness, slight for lower frequencies, but complete for tones over 1000 cycles per second. There was also evidence of cerebral cortical dysrhythmia and irritation in the electroencephalogram (EEG) as well as gastroduodenal changes. The report did not state whether the hearing improved, only that the individual returned to work.

St. Hill [39] relates the case of a man who died following exposure to trichloroethylene in the course of baling out tanks in a ship's hold. The material being removed from the tanks was condensate from the ship's steam supply, the condenser having been cleaned recently with trichloroethylene. The man worked a total of about twenty hours at this task at the end of which time he complained of headache, dizziness, double vision, and paralysis of the face and neck muscles. The paralysis continued to the point that the man had to be fed intravenously and placed on a mechanical respirator and eventually died several weeks after the incident. Two other men who had worked with the victim experienced similar but less severe symptoms. Weakness and numbness of the face persisted in one of the two men for several months after the exposure. Blurring of vision and diplopia were reported by Maloof [40] in a worker the day after he had been

engaged in retrieving a basket containing metal parts which had dropped into a degreasing tank containing hot trichloroethylene. In addition to symptoms characteristic of effects on the central nervous system and the visual effects, the worker received first and second degree burns to the skin and first degree chemical burns to the eyes which the author ascribed to trichloroethylene vapors from the degreasing tank.

Mitchell and Parsons-Smith [41] reported the case of a man operating a metal degreaser who lost his sense of taste but not smell after one month's exposure to concentrations of trichloroethylene which "occasionally escaped in sufficient quantity to be visible." Two months later he developed trigeminal analgesia and EEG cortical changes which had not cleared up during the two years of the authors' study.

The first published records of chronic occupational overexposures to trichloroethylene in the United States summarized ten individual cases occurring prior to 1944. [42,43] All cases exhibited the general symptoms characteristic of central nervous system disturbances, [43] including one case of total blindness. [42] Duration of exposures ranged from 2.5 hours to 2 years. All workers had been engaged in activities which used trichloroethylene either as a dry-cleaning or degreasing solvent. No quantitative estimations of exposures were provided.

Kunz and Isenschmid [44] cited the case of a worker who removed diamond powder from the rolls of a jewelry mill using

trichloroethylene; an estimated 100 to 300 milliliters of the solvent evaporated directly in front of his face daily. There were increasing changes in vision and color perception leading to blindness within a year after the last known exposure.

McBirney [45] reported that six women working with trichloroethylene to remove small spots of wax remaining on optical lenses reported handling difficulties because of an inability to feel the lenses properly. Subsequent examination indicated a total loss of tactile sense, loss of motion, and inability to grasp objects between the thumb and fingers. Similar findings were reported in the case of a man who operated a degreasing tank which utilized a solvent comprised of 40% trichloroethylene and 60% dichloroethylene. Diplopia was reported in the latter case as well.

With the advent of electroencephalographic (EEG) and psychophysiological testing techniques the question of permanent damage to nerve tissue has been considered more seriously. Fra et al [46] reported a case of chronic poisoning in which electromyographic tests showed peripheral nerves to be intact but some facial muscle changes indicating involvement of the brain stem structures.

Kylin et al [22] measured optokinetic nystagmus to demonstrate the effect of trichloroethylene on the central nervous system. He showed changes in 12 subjects after two hours exposure to 1000 ppm. This test was shown to be a less sensitive indicator of effects of trichloroethylene than of effects of alcohol.

Todd [47] reported the case of a man who had ingested unknown amounts of trichloroethylene. After prolonged unconsciousness and some cyanosis, the result was a temporary paranoid psychosis and a distortion of both vertical and horizontal vision so that persons appeared 12-18 inches high, an effect described as "Lilliputian hallucinations".

(c) Effects on the Cardiovascular System

James [37] reported the case of a man who apparently had become addicted to trichloroethylene vapors in the course of his work at a degreaser. The man's death, which occurred seventeen hours after his last known exposure to trichloroethylene, was due to cardiac arrest attributable to trichloroethylene.

Deaths in four of the five fatal cases of trichloroethylene poisoning reported by Kleinfeld and Tabershaw [36] were attributed to ventricular fibrillation. In all of these cases the men had worked on degreasers and had died suddenly at work or within a few hours after leaving the plant, following complaints of nausea, drowsiness, dizziness, and vomiting.

Bell [48] cited the case of an operator of dry cleaning equipment who died suddenly after mild exertion (starting a motorcycle and riding it a few hundred yards) upon leaving work. The author estimated that the man had been exposed to concentrations of trichloroethylene as high as 4500 ppm prior to his death which was attributed to ventricular fibrillation.

Bardodej and Vyskocil [21], Ogata et al [25], Andersson [26] and others have noted that exposure to trichloroethylene may either speed or slow the heart rate, depending on the degree of exposure. Andersson noted that 77 of 104 workers she studied in thirty different plants in the metal, rubber, and dry-cleaning industries showed abnormal ECG tracings with disturbance of cardiac rhythm, which she suggested might presage permanent heart damage. [26]

Bernstine [49] recorded electrocardiograms of a young marine who sustained cardiac stoppage suddenly after deep inhalation of trichloroethylene in analgesic concentration. Mouth-to-mouth resuscitation, administration of oxygen, intracardiac epinephrine and procaine, transfusion, and direct cardiac massage for 45 minutes was successful in restoring cardiac contraction, but meanwhile ventricular fibrillation was confirmed by ECG. The fibrillation shifted to ventricular tachycardia and more procaine and epinephrine were administered during the massage. One month later the marine was much improved. No follow-up was reported.

Lilis et al [50] recently offered a theory that changes in the level of epinephrine secretion associated with hypersympathicotonia induced by trichloroethylene exposure, particularly when accompanied by physical exertion or stress, might account for the cases of unexplained sudden death reported.

#### (d) Effects on the Liver and Kidneys

Secchi et al [51] found acute liver disease in three of seven cases of poisoning by accidental ingestion of trichloroethylene. They

determined that the findings could be attributed to contamination with 1,2-dichloropropane and 1,2-dichloroethane. Analysis of samples of the solvents responsible for the poisonings showed that severe liver toxicity occurred only in subjects poisoned by mixtures rich in 1,2-dichloropropane and 1,2-dichloroethane. They had found no liver damage when pure trichloroethylene was ingested.

Ten persons severely exposed to an essentially saturated atmosphere of trichloroethylene in a confined space (the hold of a ship) showed no jaundice, four patients showed hyperglobulinemia, and six hypercalcemia. Cotter [52] stated that no other liver function tests were abnormal and in all but one person the clinical test results returned to normal within two months of exposure. The author concluded that the changes in globulin levels were indicative of some degree of liver damage despite the absence of bilirubin or phosphatase retention or disturbance of the esterification of serum cholesterol.

Lachnit and Brichta [53] reported that of 22 workers (15 females, 7 males) exposed to trichloroethylene primarily in dry-cleaning shops there were three who gave positive reactions to two liver function tests (sulfobromophthalein clearance tests and colloid stability). The authors concluded that much of the clinical evidence of liver injury could be attributed to alcohol abuse and stated that the toxicity of trichloroethylene to the liver was low.

Albahary et al [54] conducted liver function tests (serum glutamic oxalacetic transaminase [SGOT], and serum glutamic pyruvic transaminase [SGPT]) on workers regularly exposed to trichloroethylene

in degreasing operations and reported that there was no evidence of liver disorders.

Guyotjeannin et al [55] studied 18 workers who were not alcoholics but were regularly exposed to trichloroethylene and had no history of preexisting liver disease by electrophoretic separation of various blood constituents. They found some abnormalities of cephalin flocculation, total lipids, and unsaturated fatty acids, and an increase in beta globulins. There was also an increase of gamma globulins. Whether or not these findings were reversible was not evaluated.

Tolot et al [56] reported the results of a comprehensive evaluation of a series of liver function tests conducted on twelve workers who had been exposed to trichloroethylene for at least five years in a degreasing shop. There was no evidence of injury to the liver even though workers were being exposed routinely to trichloroethylene "higher than the tolerance limits: 0.9 to 3 mg of trichloroethylene per liter of air."

Milby [57] noted normal tests for liver and kidney functions (SGOT, SGPT, erythrocyte sedimentation rate) in a paint stripping machine operator. Exposures to trichloroethylene were shown by subsequent sampling to have been 260-280 ppm. The hospitalized patient excreted 780 mg per liter of trichloroacetic acid on the day of the examination, indicating severe overexposure.

Armstrong [58] reported that 27 of 35 normal healthy individuals given trichloroethylene as an anesthetic showed positive evidence of

cephalin cholesterol flocculation, which also is characteristic of patients suffering from catarrhal jaundice (infectious hepatitis) and malaria. All individuals showed a negative reaction two weeks after anesthesia. The author concluded that slight liver impairment caused by trichloroethylene anesthesia is transient and less pronounced than that produced by diethyl ether.

Joron et al [59] reported massive liver necrosis with death more than one month after, last exposure to trichloroethylene estimated to have been several hundred ppm based on evaluation of simulated exposures. James [37] found some fatty degeneration of the liver in a patient whose death resulted from trichloroethylene vapors in a degreasing shop.

Gutch et al [60] described a patient who had been a chronic drinker and also had an inadvertent overexposure to trichloroethylene. The patient had evidence of acute renal failure a week after the last exposure to trichloroethylene. Needle biopsy of the kidney showed acute tubular degenerative changes; biopsy of the liver showed no evidence of cirrhosis or toxic injury. Treatment with peritoneal dialysis for ten days was successful in overcoming oliguria and renal function returned to normal. Electrocardiographic evidence of a toxic myocarditis was believed related to retention of trichloroethylene or its metabolic products. Recovery of the patient was complete without evidence of residual renal or myocardial damage.

Kleinfeld and Tabershaw [36] reported a fatality from hepatorenal failure due to accidental ingestion of trichloroethylene. Autopsy

showed marked lower nephron nephrosis severe centrilobular necrosis, of the liver, and acute pancreatitis. The man reportedly had been a heavy beer drinker.

(e) Other Effects

Friborska [61] showed that leukocyte alkaline phosphatase levels increase in persons repeatedly exposed to trichloroethylene. The acid phosphatase in blood also increased. These increases persisted after two weeks without exposure. The investigator considered that these findings might signify a defense mechanism or an increased capacity to metabolize alcohols, might be a response to changing pH of the blood, or be related to glycogen metabolism in the liver.

Bartonicek and Teisinger [62] exposed four humans for five hours to 1 mg per liter (186 ppm) trichloroethylene and analyzed their urine for metabolites. Later they exposed the same group to the same conditions, having pretreated them with three to three and one-half grams of tetraethyl thiuram disulphide (disulfiram). There was a 40-64% decrease in excretion of trichloroethanol and a 72-87% decrease in excretion of trichloroacetic acid.

Seage and Burns [63] suggested that alcohol was the precipitating factor in the production of severe abdominal pain, retching, vomiting, and pulmonary edema in a cardiac subject. The subject ingested a glass of beer and one of rum subsequent to a three and one-half hour exposure to trichloroethylene vapors arising from a bowl used to dip plastic parts.

Soucek and Vlachova [18] showed that one subject exposed to trichloroethylene after receiving 60 ml of 20% glucose and 15 units of insulin excreted 22% more trichloroethylene metabolites than when untreated. He excreted 2.6 times more trichloroethanol on the first day. Trichloroacetic acid excretion on the first day was unaffected as was the total duration of excretion.

Effects of trichloroethylene on the skin include reddening and dermographism, skin burns on contact, [40] generalized dermatitis resulting from contact with the vapor, [45] and possibly scleroderma. [64] Stewart and Dodd, [65] in a study of controlled skin exposure (thumbs), showed that unless trichloroethylene is trapped against the skin, absorption is too minute to be significant. Absorption varies with age, skin thickness and texture, as well as type of contact.

#### Epidemiologic Studies

Bardodej and Vyskocil [21] studied 75 exposed workers divided into four groups by years of exposure: less than 1 year, 1-2 years, 2-9 years, and 10+ years. Their findings showed with duration of exposure a statistically significant (P less than 0.05) increase of lacrimation, reddening of skin, and disturbances of sleep, but a decrease of sensitivity of the hands. With duration of exposure, significant increases (P less than 0.01) were found in intolerance to alcohol, tremors, "giddiness", what they termed "severer neurasthenia syndrome with anxiety states," and bradycardia.

Andersson, [26] in a detailed study of 104 persons exposed to trichloroethylene in metal, rubber, and dry-cleaning industries, described the predominant characteristics of trichloroethylene exposure as headache, dizziness, vertigo, tremors, nausea and vomiting, sleepiness, fatigue, a feeling and appearance of light-headedness or "drunkenness," increasing to unconsciousness and in some cases to death. In the Andersson series there was practically no cranial nerve involvement and only an occasional tremor of hands. Detailed correlations by sex, age, place of work, and duration of exposure and some correlations with levels of exposure and excretion of trichloroacetic acid were made. In that study, about two-thirds of workers examined exhibited signs or symptoms of effects on the central nervous system. There was some correlation between the exposure levels and the amount of urinary trichloroacetic acid excreted. Only eight of 104 workers who had been exposed to this chemical for more than three years were without symptoms. Follow-up studies of workers (some severely exposed to trichloroethylene) for three to seven years after exposure showed little residual evidence of trichloroethylene intoxication. The workers reported symptoms had subsided within four or five months after they had stopped working. On the basis of this study and a parallel study of rabbits noted below (see Animal Toxicity), Andersson concluded that 200 to 400 ppm of trichloroethylene constituted too high a standard for an eight-hour daily exposure. "At an average, continuous exposure with trichloroethylene concentrations as low as 1/10 of these ppm values,

symptoms due to trichloroethylene can be expected to appear." However, it should be noted that (1) the levels of exposure in this study were subject to many unmeasurable fluctuations, (2) the author considered that in 35 of the 104 workers studied personal "social" problems had probably affected worker findings, and (3) the trichloroacetic acid studies were not able to be correlated with the exposures sustained but only statistically compared by groups. Some mild EEG changes were evident in a few examinations but none on follow-up.

Lilis et al [50] reported a study of 70 young workers (83% less than 30 years old) exposed up to six years to variable concentrations of trichloroethylene. Environmental levels were high; 40% of 214 analyses showed levels in excess of 50 mg/cu m (about 10 ppm). However, the method of sample collection, types of samples (TWA, etc.), analytical method were not mentioned in the report. The subjects showed symptoms of "asthenia associated with vegetative disturbance." Measurements of stroke volume, cardiac output, cardiac index and cardiac activity indicated sympatheticotonus due to epinephrine. The authors also found vanillylmandelic acid excretion. For the workers studied, the following percentages of complaints were indicated: dizziness, 88%; headache, 74%; nausea, 43%; euphoria, 31%; palpitation, 29%; disturbances of vision, 21%; and sleepiness at the end of the shift, 29%. The study further showed an insidious onset after some months, up to one or two years, of the following complaints: fatigue, 68%; irritability, 56%; disturbed sleep, 46%;

anxiety, 27%; loss of appetite, 50%; alcohol intolerance, 21%. Accompanying findings included excessive sweating in 39%, palpitation in 29%, nausea in 19%, and some parasthesias. While the percentage of workers that indicated complaints are in excess of the percentage of samples at or below 50 mg/cu m (about 10 ppm), a direct relationship can not be established since the sampling protocol is unknown.

#### Animal Toxicity

##### (a) Inhalation

Rats exposed to 500, 1000, 2000, and 3000 ppm trichloroethylene for six hours daily, five times per week for six months, revealed no effects below 2000 ppm. At 2000 ppm some narcosis and lessened effort to get food was noted, but at 3000 ppm only 2 of the original 6 rats survived 6 months. [66] Dogs exposed to 2000 ppm trichloroethylene showed no adverse effects. [66] Guinea pigs exposed over 1100 hours to levels of 1200 ppm showed no changes of questionable significance in lungs, spleen, heart, adrenals or brain, and only some very slight degeneration of liver cells. [67] Siefert [68] however found liver damage in dogs exposed repeatedly for three weeks to 750 ppm. Pathological evidence of liver injury was found in the dogs examined in the third week of exposure, but not in the dogs which survived five weeks after the last exposure. Reexposure at 200 ppm did not cause recurrence. Dogs exposed to 500-750 ppm also showed liver changes in the eighth week. [68]

Hunter [69] found that of ten mice exposed to 10000 ppm for one hour in repeated exposures, six died but several about to die could be

revived if subjected to a high oxygen concentration. No liver damage was found and the deaths were considered due to anoxemia from shallow respiration. Andersson [26] found no evidence of liver injury in rabbits exposed to trichloroethylene in a series of five studies: (1) 12 mg/liter (2200 ppm) 5 hours per day for 8 months; (2) 37 mg/liter (6900 ppm) for about 4 hours per day for 8 months; (3) 55 mg/liter (10200 ppm) for approximately one hour per day for 8 months; (4) 80 mg/liter (14900 ppm) for about 30 minutes per day for 12 months; and (5) 190 mg/liter (35300 ppm) for 5-10 minutes per day for 9 months. Kylin et al [70] saw no liver damage in rats after single exposures to 3200 ppm. In addition these investigators studied mice exposed to 1600 ppm, four hours daily, six times a week for periods of one, two, four and eight weeks; twenty mice were exposed in each of the four subgroups. Fatty degeneration of the liver was slight and tended to abate after two weeks of exposure.

Nowill et al [71] exposed one dog, three rats, and three rabbits to concentrations of 500 and 1000 ppm trichloroethylene for about 18 hours daily for 90 days. Liver function tests, blood and routine urine tests, activity, growth rates, and post-mortem tissue studies showed no abnormalities.

Andersson [26] exposed rabbits for a half hour to four hours daily to 37 mg/liter (6900 ppm) for eight months and noted an increasing frequency of anesthesia. It also occurred after shorter periods of daily exposure, and recovery required a significantly longer time after the study had been in progress for a few months.

Reversible heart changes were found by Andersson in rabbits exposed up to 12 months to varying daily concentrations of trichloroethylene. Krantz et al [34] by perfusing hearts of rats, frogs, and dogs demonstrated no effect of trichloroethylene on coronary circulation or heart oxygen consumption.

Adams et al [72] showed that the highest levels of exposure with no effects on rats were: 0.3 hour at 20000, 0.6 hour at 12000, 1.4 hour at 4800, and 5 hours at 3000 ppm. For repeated exposures of 7 hours a day, 5 days per week the no-effect levels were: monkeys 400 ppm, rats and rabbits 200 ppm, and guinea pigs 100 ppm. No-effect levels were also determined by Prendergast et al [73] for rats, guinea pigs, rabbits, dogs, and monkeys at 730 ppm, eight hours daily, five days per week, for 30 exposures (though dogs had less growth than controls) and 90-day continuous (24 hours a day) exposures to 35 ppm. After comparison with control animals, slight liver weight increases were noted but there were no microscopic changes.

In early 1962, Desoille et al [74] showed in tests on 10 rabbits that acute exposure (15-60 minutes at concentrations ranging from 7000 to 14000 ppm) to trichloroethylene gave EEG changes indicative of several degrees of irritation from minor ones up to electroclinical epileptic seizure. The authors also noted that the rabbit is more susceptible to epileptic seizures than other species. Later in the same year, Desoille et al [75] utilized EEG's to study rabbits with chronic alcohol intoxication that were also subjected to trichloroethylene. Graver functional cerebral disturbances of longer

duration were noted in those animals intoxicated with alcohol, even though the trichloroethylene given after alcohol was half the strength used in the single exposures performed earlier. [74]

Studies of effects on blood and bone marrow were performed by Mazza and Brancaccio [76] in 12 rabbits exposed to 15 mg/liter (2790 ppm) of trichloroethylene for four hours per day, six days per week for 45 days. The characteristics of the hemochromocytometric tests and the description of the bone marrow led the authors to the conclusion that chronic intoxication to trichloroethylene has a direct action on the bone marrow and thus causes myelotoxic anemia.

Another factor studied was dehydration before trichloroethylene exposures. Baetjer, [77] in careful hypothalamic self-stimulation performance tests, showed that a three-day dehydration caused rats to make fewer responses than nondehydrated rats. After exposure to trichloroethylene, neither group performed as well as before exposure. The dehydrated rats performed better than the nondehydrated rats, although some tolerance for trichloroethylene developed in both groups. Recovery of nondehydrated rats was prompt after moderate exposures but was not completed in 24 hours, suggesting that either the trichloroethylene concentration in the brain was greater or the dehydrated brains were more resistant to trichloroethylene or both. Ten-day dehydration tests and trichloroethylene exposure resulted in further decrements in performance after the fifth day of exposure, suggesting that high concentration of trichloroethylene combined with dehydration may have produced some residual brain damage.

Behavioral techniques have been devised to study further the effect of trichloroethylene and its metabolites on animals. Grandjean, [78] using food as the stimulant to rats, was unable to show behavioral changes related to trichloroethylene exposures at levels of 200 or 800 ppm. They showed some increased excitability or disinhibition with exposure to trichloroethylene at the levels studied. Battig and Grandjean [79] exposed rats to 400 ppm trichloroethylene for eight hours, five times weekly. This did not affect their general condition but swimming speed after exposure was reduced. However, exploratory behavior seemed increased. In a later work, Grandjean [80] exposed rats for six hours to 400 ppm. Immediately after exposure there were slight decrements in performance of swim tests under load and 800 ppm gave significant decrement and evidence of fatigue compared to unexposed control rats. No difference was present one hour later. At 1600 ppm for six hours rats had a persistent decrement in performance tests and showed fatigue. The rats during their five-hour exposures at the three levels of 400 ppm, 800 ppm, and 1600 ppm showed 81, 65 and 58% of normal activity, respectively. Goldberg and co-workers [81] trained rats in avoidance responses. Four-hour exposures, five days per week for two weeks resulted in appearance of slight imbalance but no difference, in responses to 200, 560, and 1580 ppm; learning appeared to be stimulated by 200 ppm exposures. Decreased avoidance responses were present at 4380 ppm. Exposures to 1568 ppm disturbed growth.

(b) Injection

By using 40-45 mature rats and 30 control (unexposed) rats and sacrificing them at two-hour intervals for 168 hours, Wirtschafter and Cronyn [82] showed that rats injected with 0.004 mole/kg trichloroethylene had changes at 12-16 hours which were reversed at 24 hours. The changes included raised levels of SGOT, indicative of functional hepatic changes, and microscopic evidence of liver cell damage. No subsequent changes were present. Mikiskova and Mikiska [83] studied guinea pigs intraperitoneally injected with trichloroethylene or with trichloroethanol. The animals subsequently given tests of electric stimulation for skin, spinal reflex excitability, excitability of motor cortex, and EEG and ECG recordings showed that trichloroethanol results were similar to those of trichloroethylene but at least three and probably five to six times more effective. The authors advanced the theory that trichloroethylene effects were in part due to trichloroethanol. They further established that trichloroethanol was twice as effective as trichloroethylene in slowing the heart rate. They noted that the conjugation of trichloroethylene with glucuronic acid is reversible, that the trichloroethanol produced deep anesthesia within 5-10 minutes which lasted 3/4 to one hour, whereas trichloroethylene took 15-30 minutes to produce lighter anesthesia but it lasted two to three hours.

Bartonicek and Brun [84] made extensive studies of brain tissue, EEG, acid phosphatase levels, and erythrocyte sedimentation rates in two groups of rabbits. In one group, rabbits were injected with 3 ml

trichloroethylene into the muscle three times per week for 29 days (a total of 53 g per rabbit). The second group was given 2 ml trichloroethylene twice a week for periods lasting from 41 to 247 days, or a total of 18-133 g per rabbit. Controls were also studied. Acid phosphatase was increased after exposure. Brain slices and sections of peripheral nerves were examined histologically and histochemically. The 29-day exposure group, and even more the 41-to-247-day exposure group of rabbits, showed widespread eosinophilic homogenization of cytoplasm, shrinkage of cytoplasm, and nuclear hyperchromasia suggesting anoxic ischemic nerve cell damage. No severe neurological disturbances were noted.

#### (c) Metabolic Studies

In 1938, Barrett et al [67] had shown that trichloroacetic acid was excreted in urine after inhalation of trichloroethylene. Thereafter many animal studies were undertaken to determine the metabolic pathways involved, especially after Powell [17] developed the Fujiwara reaction with pyridine and alkali as a method of studying the time course of elimination of trichloroethylene and its metabolites. Butler [14] showed that dogs excreted not only trichloroacetic acid but also trichloroethanol conjugated with glucuronic acid as urochloralic acid and postulated the metabolic pathway through chloral to trichloroethanol. He then gave dogs intramuscular injections with 5 g trichloroethanol per kg of body weight. Sixty-five percent of the dose was excreted in the first three hours at a maximum rate of 23 mg per hour in the first hour. Trichloroacetic

acid was also excreted but in much smaller quantity. Friberg et al [24] showed that rats exposed for four hours to 640, 1150 or 2500 ppm excreted trichloroacetic acid increasingly up to 24 hours after exposure then decreasingly for up to six days irrespective of dosage. Studies by Forssman and Holmquist [85] showed that rats exposed for 36-60 minutes to 59-86 mg/liter (11000-16000 ppm) of trichloroethylene exhaled 32-69% of the total inhaled during exposure. Of the retained trichloroethylene at low exposures, 21-28% was excreted as trichloroethanol and 1.2-3.9% as trichloroacetic acid. With higher exposures, 32-69% was exhaled as trichloroethylene and 3.2-7.8% as trichloroacetic acid. Forssman et al [86] further showed that pretreatment with disulfiram (antabuse) in rats did not affect the excretion of injected sodium trichloroacetate, but did stop the excretion of trichloroacetic acid after inhalation of trichloroethylene. They attributed this to an inhibition of the oxidation of chloral to trichloroethanol. Bartonicek and Soucek [87] studied rabbits' metabolism for a year and concluded that their metabolism was qualitatively like humans and only the relative quantities differed. Rabbits excreted 10 times more trichloroethanol than trichloroacetic acid and about 50 times less trichloroacetic acid than man, but equally slowly.

Fabre and Truhaut [88] studied tissue homogenate. They found trichloroethylene in all tissues obtained during exposure, greatest in fat, then in lungs, spleen, liver, and least in brain and kidney. Trichloroacetic acid was present in greatest concentration in fresh

spleen, suprarenal glands, reproductive organs, and urine. In vitro studies of tissue homogenates exposed to trichloroethylene showed the most active conversion of the substance to its metabolites in the spleen, and decreasing activity in the lung, brain, liver, and kidney tissues.

In 1967 Leibman and McAllister [89] reported studies with liver microsomal tissue extracts. They were able to show that there was an increase in the ability to metabolize trichloroethylene to chloral and to trichloroethanol when the animals from which the tissue extracts were obtained had been previously treated with phenobarbital. Rats pretreated with phenobarbital and then exposed to trichloroethylene also excreted more metabolites in the first few hours than the similarly exposed but not pretreated controls. The authors pointed out that drug intake might vitiate conclusions drawn from levels of trichloroacetic acid urinary excretion based on single samples.

#### Correlation of Exposure and Effects

The most meaningful studies for purposes of establishing a well-defined cause-and-effect relationship are those in which an attempt has been made to relate the environmental exposures with subsequent effects in the exposed population.

Longley and Jones [90] reported that unconsciousness suddenly occurred in a worker who entered a tank in which a paint containing in excess of 75% trichloroethylene had been recently used. An attempt was made to simulate conditions which produced the unconsciousness and air sampling was conducted within the tank after application of some

of the paint. Concentrations of trichloroethylene within the tank varied by location between 1700 and 3300 ppm. The authors estimated that a concentration of 3000 ppm would cause unconsciousness in human subjects after a 10-minute exposure.

Kleinfeld and Tabershaw [36] reported five cases of fatalities resulting from acute overexposure to trichloroethylene in degreasing operations. In only one case was environmental data available (taken subsequent to the incident). In that case, concentrations of trichloroethylene ranging from 200-8000 ppm were measured. The workers in this case had continued to work at his job despite symptoms and complaints of nausea, drowsiness, dizziness, and vomiting, and died suddenly within a few hours after leaving the plant. Death was attributed to ventricular fibrillation.

Kylin et al [22] exposed 12 volunteers to 1000 ppm of trichloroethylene for two hours. Based on the development of optokinetic nystagmus, it was concluded that exposure had had an effect on the central nervous system but much less marked than in similar tests with alcohol.

Vernon and Ferguson [91] reported the results of experimental two-hour exposures of 8 young male volunteers (aged 21-30) to concentrations of 0, 100, 300, and 1000 ppm of trichloroethylene. On the basis of various psychophysiological tests including flicker-fusion, Howard-Dolman depth perception, Purdue Pegboard, Muller-Lyer form perception, a written test of the "code substitution" type, and groove-type steadiness tests, decrements in performance were reported

statistically only at 1000 ppm. One subject exposed at 300 ppm complained of lightheadedness and dizziness.

Stopps and McLaughlin [92] reported the results of psychophysiological testing of one human subject exposed for 2-1/2 hour periods to concentrations of 100, 200, 300, and 500 ppm of trichloroethylene. Tests used were the Crawford small parts dexterity test, Necker cube test, card sorting tests, and a dial display test. Their studies indicated no significant effect on psychomotor performance at the 100 ppm level. There was a slight decline in performance at the 200 ppm level which became progressively more pronounced at the 300 and 500 ppm concentrations.

Stewart et al [29] reported the results of two experiments in which seven human volunteers were exposed to varied concentrations of trichloroethylene. In the first experiment the concentrations ranged between 160 and 400 ppm for a total exposure period (apparently including equilibration time) of 83 minutes. The time-weighted average concentration for this test was 265 ppm. In the second experiment the concentration ranged between 172 and 332 ppm for a total of 190 minutes of exposure. The time-weighted average concentration was 211 ppm. Subjective and psychophysiological responses from the seven subjects used in these experiments were recorded during the exposures. Transient, mild eye irritation was reported by three of the seven subjects only at the lowest concentration (160 ppm). Between 160 and 250 ppm the odor was constantly perceptible but not unpleasant; there were no reports of lightheadedness. Between 350 and

400 ppm two of the seven subjects reported lightheadedness although the results of Romberg and "heel-to-toe" tests were normal in all subjects.

In a later study, Stewart et al [30] conducted a series of experimental 7-hour exposures of five human subjects to a nonfluctuating 200-ppm level of trichloroethylene on five consecutive days. After 30 minutes two subjects complained of throat dryness and one of mild eye irritation. No untoward objective responses were observed during any of the exposures, although on one or more occasions 50% (sic) of the subjects reported that greater effort was required for them to perform normally in a modified Romberg test. The investigators reported that the results of the performance tests, ie, the Crawford manual dexterity tests and the Flanagan coordination and inspection tests, were normal. One consistent response was the complaint of "feeling fatigued" on the fourth and fifth days of the exposure. The authors concluded that the significance of reported fatigue and drowsiness may well be of clinical significance and merit further investigation. Laboratory tests for liver cell damage did not even suggest transient effects.

Salvini et al [93] exposed 6 male university students (between 20 and 22 years of age) to an average concentration of trichloroethylene of 110 ppm (a range of 90 to 130 ppm) in two four-hour sessions separated by 1-1/2 hours. During exposure complex performance tests of perception, memory, and manual dexterity were conducted. Each subject was examined on two different days, one day in the test atmos-

phere containing trichloroethylene and the other in a control atmosphere containing no trichloroethylene. During the trichloroethylene exposure periods, the vapor was circulated periodically into the test room and the air was analyzed at regular intervals by gas chromatography. The investigators concluded that there was a statistically significant (P less than 0.05) decrement in performance, without clinical signs or symptoms, indicating that 100 ppm was very close to the average concentration capable of interfering with psychophysiological efficiency. The entire experiment was repeated using 6 workmen who regularly worked with trichloroethylene. The results of this second test confirmed the conclusions drawn from the results using the university students.

To this point, this discussion of attempts to correlate environmental concentrations and consequent effects has been limited to cases of acute overexposures in industry or voluntary human exposures to controlled environments. Relatively few studies have been conducted in industry in which attempts have been made to document chronic environmental exposure conditions and the resulting health effects in the exposed population. Grandjean et al [27] reported a study in which a total of 73 workers in 24 different workshops were examined. A relatively high frequency of subjective complaints, alterations of the involuntary nervous system and of neurological and psychiatric symptoms were reported. The frequency showed a good relationship with total duration of exposure (months on the job). A total of 96 air samples were collected during the study,

the results of which ranged between 1 and 335 ppm, many of them lying between 20 and 40 ppm. The authors stated that a series of consecutive samples collected during a period of 3 to 4 hours in one workplace showed a great variation in concentrations due to the actual degree of ventilation and utilization of the degreasing apparatus. The authors admitted that air measurements provided insufficient indication of the total exposure. Laboratory tests of hepatic function showed no significant changes. On that basis they stated that they could not conclude that there was any causal relationship between liver troubles and exposure to trichloroethylene.

Bardodej and Vyskocil [21] reported a statistically significant (P less than 0.01) correlation of the following symptoms with length of exposure in dry-cleaning and degreasing occupations in a total of 75 workers studied: intolerance to alcohol, tremors, giddiness, bradycardia, and "severer neurasthenic syndrome with anxiety states." The authors reported that the atmospheric concentrations of trichloroethylene in these plants varied between 0.028 and 3.4 mg per liter (5 to 630 ppm). At high environmental levels there was agreement on reported symptoms with other authors. However, Bardodej and Vyskocil reported some response at low levels. In their study, no controls were used, the number and frequency of environmental samples was not given, the areas sampled were not reported, and the general health of the worker population studied was not given. Although not considered statistically significant, some percentages of reported symptoms were given for ranges of exposure. For a group of 12

drycleaners exposed to 0.16 to 3.4 mg per liter (about 30 to 630 ppm), 75% complained of headache, 92% intolerance to alcohol, 83% disturbance of sleep, 92% fatigue, 33% bradycardia (below 60 beats per minute), 8% conduction disturbance (ECG), and 8% heart muscle disturbance (ECG). Nineteen degreasers exposed to 0.54 to 0.83 mg per liter (about 100 to 154 ppm) reported the following percentages of symptoms: 26%, headache; 63%, intolerance to alcohol; 26%, disturbance of sleep; 47%, fatigue; 40%, bradycardia; 16%, condition disturbances (ECG); and 5%, heart muscle disturbances. Another group of 36 degreasers were exposed to 0.028 to 0.055 mg per liter (about 5 to 10 ppm) and reported the following: 67%, headache; 22%, intolerance to alcohol; 22%, disturbance of sleep; 61%, fatigue; 16%, bradycardia; 3%, conduction disturbances; and 3%, heart muscle disturbances.

For the most part the results of experimental exposures of animals to trichloroethylene have been consistent with effects in humans exposed to equivalent concentrations. Exposures of rats and mice to concentrations of trichloroethylene in excess of 3000 ppm resulted in immediate narcosis or death after one to six hours exposure. [24,66,69,72,81] Varying degrees of intoxication by inhalation of trichloroethylene have been reported by various investigators and discussed in the previous section.

In published case reports, [36,60] it has been suggested that ingestion of alcohol may potentiate the effects of trichloroethylene intoxication. This is a clinical impression of industrial physicians and has not been adequately demonstrated.

#### IV. ENVIRONMENTAL DATA AND BIOLOGIC EVALUATION

##### Air Sampling and Analytical Methods

Methods of collection of trichloroethylene in air have included use of evacuated gas sampling flasks, [94] plastic bags, absorptive liquids such as pyridine or toluene [95-97] and silica gel or activated carbon adsorbents. [98-103] Field methods for the estimation of trichloroethylene vapor concentrations have included the use of the Davis Halide Meter and direct reading colorimetric indicator tubes. [104,105]

The analytical methods for determining trichloroethylene fall into three classes: physical methods such as interferometry or gas chromatography; chemical methods which depend on the reaction of trichloroethylene with a chemical reagent; and destructive methods such as the combustion techniques which decompose trichloroethylene and liberate hydrochloric acid. [95]

Adsorption on activated charcoal offers the greatest efficiency and ease of collection. [98,101-103] of absorbing liquids is inconvenient for obtaining breathing-zone samples, especially when two or more scrubbers must be connected in series to assure high collection efficiency. [95,96] The use of plastic bags or evacuated containers for collecting air samples may result in a loss of sample due to adsorption on the walls or to permeation through the plastic or around the joints in addition to being inconvenient for transport to the laboratory for analysis. Excessive water vapor tends to displace

the chlorinated hydrocarbons from silica gel when it is used as an adsorbent in a humid atmosphere. [106]

Gas chromatography offers the greatest specificity and sensitivity of the various methods of analysis, and is the method of choice. [101,102,106,107] The other methods including the field methods are subject to interferences from a wide variety of compounds, particularly other chlorinated solvents or other chloride-containing compounds and are useful only if trichloroethylene is the sole contaminant. [97,104] There are direct reading instruments which are not recommended for compliance purposes, but may be useful for emergencies, engineering control studies, and for estimation purposes. The Scott-Davis Halide Meter, and equivalents, have been used to determine trichloroethylene vapors in air. It is a nonspecific method and must be calibrated prior to each use. Detector tubes manufactured by several companies have been used to estimate trichloroethylene atmospheric concentrations. Care should be taken in using these tubes and each batch must be calibrated just prior to use. These are nonspecific as there are numerous interfering chemical contaminants and they are also affected by variations in temperature and humidity. Portable gas chromatographs are highly specific for trichloroethylene; however, they are very costly and can be used only by a well-trained investigator.

#### Environmental Data

Since 90% of the trichloroethylene produced in the United States is used in vapor degreasing operations, the majority of the limited

available environmental data were obtained from such operations. There are no published reports of environmental levels experienced in manufacture of trichloroethylene. The purpose of this section is to investigate the feasibility of controlling exposures to trichloroethylene to within the recommended standard. The sparse number of surveys and differing methods of analysis limit the discussion to chronological presentation of control methods and their effectiveness. Later in this section are suggestions for improving controls. Specific suggestions are avoided because of the variability of processes, equipment, climate.

In 1943 Morse and Goldberg [108] reported results of a study of chlorinated solvent exposures in different degreasing plants. Three types of controls were encountered: Type I, degreaser tanks equipped with both local exhaust ventilation and condenser coils to condense the vapor; Type II, tanks with condensers but no local exhaust ventilation; and Type III, tanks with no local exhaust ventilation and no condenser. The effectiveness of engineering controls is demonstrated in the following results. The general average for total atmospheric chlorinated solvents was 96 ppm (range 5-393) for Type I, 135 ppm (range 3-900) for Type II, and 221 ppm (range 24-880) for Type III. It was emphasized that perchloroethylene was used with trichloroethylene and sampling was done for total chlorinated solvents, not trichloroethylene exclusively.

Grandjean et al [27] measured trichloroethylene concentrations in workshops using degreasing tanks. All of the tanks studied were

equipped with refrigerated coils and exhaust systems. Atmospheric concentrations near the tanks varied from 20 to 40 ppm. Grandjean reported the operation of cold trichloroethylene vats wholly lacking in safety devices or any ventilation system on two occasions. Concentration of trichloroethylene in the air varied from 67 to 157, averaging 105 ppm.

As part of this study the effectiveness of different types of engineering control was evaluated. Air analyses were made using various methods of ventilation while normal work was performed. The workshop tank under consideration was fitted with a mixed system of mechanical ventilation including both air suction and air blowing. On the upper edge of the trichloroethylene tank there was a fixed lateral exhaust system which was intended to remove the rising trichloroethylene vapor. With no ventilation the average concentration of trichloroethylene in the air was 167 ppm. With the lateral exhaust system at the end of the tank operating, the average concentration was reduced to 112 ppm. The average concentration was lowered further to 53 ppm when general ventilation was used in conjunction with local exhaust. Atmospheric values of trichloroethylene showed a great variation with the degree of ventilation and utilization of the ventilation equipment. Atmospheric trichloroethylene samples were taken with impingers, and measured colorimetrically using the Fujiwara reaction. [27]

Grandjean also studied atmospheric concentrations during the cleaning of tanks and reported the following: "Trichloroethylene

equipment is cleaned once or twice a week. We examined the concentration of trichloroethylene near the tank during one cleaning operation. In the case in question, the workman emptied the tank, rinsed it with water from a powerful hose pipe, then got inside the tank and spent half an hour cleaning with a scrubbing brush. Analyses of the air showed a concentration of 1,120 ppm outside the tank while the hose pipe was in action, with 815 and 395 ppm inside the apparatus during and after the scrubbing respectively."

Skinner [109] reported the use of baffles on windows near degreasers in the plant to control high velocity drafts. Trichloroethylene concentrations of 170 to 230 ppm were reduced to 30 to 40 ppm with this approach to control.

Hargarten et al [110] reported results of tests carried out from 1952 to 1957 around 43 degreaser operations. Ninety-three percent of the operators' breathing zone samples taken during the cleaning cycle of the degreasers were 100 ppm or less. Methods of sampling and analysis were not stated.

In a 1963 report Ahlmark et al [111] found that during the preceding decade, when 570 degreasing plants were inspected in Sweden, the average trichloroethylene concentration exceeded 30 ppm in only 3% of the cases. A more intensive study was then performed on 18 degreasing tanks at 14 works. The breathing zone samples taken with a Davis Halide Meter and with LKB Halogen Detector Tubes are presented in Table X-3 along with relative exposure times for different operations. The mean exposure to trichloroethylene was 50 ppm (range

0-400) for degreasing operations while the highest mean value was 225 ppm (range 10-375) in the cleansing operation.

There are no published environmental data on trichloroethylene concentrations in other industries beyond the descriptions of health hazards associated with the use of this solvent in those industries. Thus, the effectiveness of engineering controls can be demonstrated only for degreasing operations.

### Engineering Controls

Industrial or commercial operations that use trichloroethylene have one or more methods available to control the emission of solvent vapors into the general work environment. The strategy of controlling hazardous industrial levels of trichloroethylene includes the following:

1. Substitution of less harmful solvents
2. Proper equipment design
3. Process location
4. Process ventilation
5. Proper operating, maintenance, and waste disposal procedures

1. Substitution

In solvent using industries it is common practice to substitute a solvent with a less toxic one. Full consideration must be given to other solvent properties such as effectiveness, relative volatility, volume of air required to dilute the vapor in the work environment to

a safe level, relative amounts of each solvent required for the task, likelihood of control of the vapor concentrations, and flammability.

## 2. Equipment design

Hazardous environmental conditions result from solvent escape, resulting from solvent evaporation, carry-out and spills, both those accidental and those incidental to operations, especially in degreasers. It is imperative that the evaporation and condensation of solvents be carefully controlled by balanced heat inputs. Careful and proper design of process operations is still the simplest and most economical method for controlling dangerous vapor emissions.

## 3. Process location

Process location is one of the most often overlooked and yet most effective methods of minimizing dangerous trichloroethylene vapor levels in the work environment. For example, degreasing operations should be installed in large rooms with good general ventilation wherein the entire work area is constantly flushed with sufficient uncontaminated air to dilute the toxic vapor and thus, in conjunction with local exhaust ventilation render the workroom atmosphere harmless. Areas in the vicinity of doors, windows, or other possible sources of draft conditions should be avoided since excessive air movements in the vicinity of trichloroethylene operations could decrease the effectiveness of local exhaust systems and thus enhance the possibility of vapor escape. Location of trichloroethylene operations in the vicinity of high temperature from high energy sources should be avoided to reduce the possibility of decomposition

of trichloroethylene into chlorine, hydrogen chloride, or the very toxic gas, phosgene.

#### 4. Process ventilation

Ventilation is by far the most common engineering method for controlling solvent vapors. Vapor recovery systems are sometimes used when a high airflow exhaust system is required for good ventilation.

#### 5. Proper operating, maintenance, and waste disposal procedures

Trichloroethylene losses from industrial operations can be minimized by proper operating procedures and careful supervision. Factors such as the rate of work entering and leaving the vapor zone and the shape of the parts can be critical to the degree of vapor emissions from degreaser operations as indicated in a report by Grandjean et al. [27]

#### Biologic Evaluation

Biologic monitoring is not part of the recommended standard although such monitoring is used in much of the research dealing with trichloroethylene exposure. Methods used in establishing a diagnosis of exposure to trichloroethylene are based upon the direct analysis of this chlorinated hydrocarbon in the blood or in the breath [17,29,30] or the determination of its metabolites, monochloroacetic acid, trichloroacetic acid or trichloroethanol, in the blood or urine. [18,23, 30,112,113] The determination of trichloroethylene in blood samples is generally not considered to provide a reliable index of exposure because of its rapid conversion to several metabolites. [17,29] The

concentrations of individual metabolites found in blood or urine provide very little correlation with levels of exposure among individual human subjects. [18,30,112]

The measurement of trichloroethylene in the expired air of subjects exposed to different, nonfluctuating vapor concentrations of this solvent in the postexposure period offers promise as a good index of exposure levels. The concentration of trichloroethylene in the breath in the immediate postexposure period represents washout from the lungs and indicates the concentration of the vapor to which the subject was exposed most recently. A breath sample collected approximately three hours after the exposure is considered to provide a concentration of the solvent which is directly related to the time-weighted average vapor exposure. [30] Thus, breath analysis is particularly valuable in the prompt examination of a case of suspected overexposure but it may also prove useful in estimating a time-weighted average exposure when serial analyses of the breath are made on an individual. Since the concentration of trichloroethylene in the breath is influenced further by the duration of the exposure period, concentration-time relationships must be worked out.

## V. DEVELOPMENT OF STANDARD

### Basis for Previous Standards

In 1943 the United States Public Health Service [114] published its Manual of Industrial Hygiene and Medical Service in War Industries which listed "maximum allowable concentrations" for several contaminants of the workroom atmosphere. These values were based on cumulative knowledge and collective experience developed in the field of industrial hygiene. Trichloroethylene was given a limit of 200 ppm with the indication that this value was the maximum allowable concentration most widely accepted at that time based on an 8-hour daily exposure.

The list of acceptable concentrations from the same manual was critically reviewed, unified, and extended by Cook [115] in 1945. This list was supplemented by lists of acceptable concentrations supplied by other sources including the California Industrial Accident Commission, the American Standards Association, and the states of Connecticut, Massachusetts, New York, Oregon, and Utah. Each of these sources listed a value of 200 ppm as the maximum acceptable concentration for trichloroethylene. Cook, who also recommended the 200 ppm maximum allowable concentration, cited the works of Seifter [68] and Morse and Goldberg [108] as the bases for his standard.

The Z-37 Committee of the American Standards Association, now the American National Standards Institute, published its standard for trichloroethylene in 1946. The Committee recommended a maximum allowable concentration of trichloroethylene of 200 ppm for an 8-hour

workday. In 1967 this standard was revised by the Z-37 Committee. [116] The revision established 100 ppm as an acceptable time-weighted average concentration for an 8-hour workday. In addition, an acceptable ceiling concentration of 200 ppm, provided that the time-weighted average is kept at or below 100 ppm, was recommended. Furthermore, a concentration of 300 ppm for a duration of not more than 5 minutes was judged acceptable if encountered not more than once in 2 hours during an 8-hour workday. These standards are based on the reports of von Oettingen, [9] Adams et al, [72] Stewart et al, [29] and Kleinfeld and Tabershaw. [36]

The American Conference of Governmental Industrial Hygienists (ACGIH) [117] Threshold Limit Value (TLV) for trichloroethylene was 200 ppm from 1947 to 1961. In 1961 it was lowered to 100 ppm based on the report of Adams et al [72] that there is an extremely small probability of adverse effects on human subjects if the vapor concentrations of trichloroethylene are kept below 100 ppm.

The Hygienic Guides Committee of the American Industrial Hygiene Association [6] has recommended a concentration of 100 ppm of trichloroethylene for a time-weighted average concentration for a normal workday, based on human experience and animal studies, which further indicates that fluctuations of the concentrations should be kept below 200 ppm.

The Occupational Safety and Health Administration, Department of Labor, has adopted a standard for trichloroethylene of 100 ppm for an 8-hour time-weighted average, 200 ppm for an acceptable ceiling

concentration, and 300 ppm for an acceptable maximum peak above the acceptable ceiling provided that it occurs no more often than 5 minutes in any 2 hours. These were developed from and based on the current American National Standards Institute Z-37 limits. [116]

Some European investigators have recommended occupational health standards for trichloroethylene of less than 75 ppm. However, in most cases these recommendations were based on gross estimations of environmental conditions based on extrapolations from the results of biological sampling (analysis of blood or urine for metabolites of trichloroethylene). Where air sampling was conducted the investigators stated that concentrations varied greatly during a normal workday. A summary of the environmental standards, ranging from 2 to 200 ppm, promulgated by foreign countries is presented in Table X-4. [118]

#### Basis for Recommended Environmental Standard

The number of studies in which comprehensive environmental surveys have been supplemented with a well planned surveillance program for adequate numbers of workers exposed to trichloroethylene are so few that it is difficult to establish an environmental standard based upon unequivocal scientific data. Much of the information correlating exposure and effects have been obtained through experimental studies with human volunteers. [22,29,30,91-93] Such studies are necessarily limited in the total duration of exposure and thus valuable primarily for evaluation of short-term effects, that is

exposure to tolerable concentrations of a substance for relatively short periods of time, up to 5 days.

It is apparent from the literature that exposures to concentrations between 200 and 500 ppm for periods of time less than the normal workday will result in symptoms of "prenarcosis" as well as mild irritation of the upper respiratory tract. This is corroborated by the previously mentioned reports of Stewart et al [29,30] and Stopps and McLaughlin. [92]

The studies with trichloroethylene most relevant directly to the development of an occupational standard are those in which human volunteers were exposed to carefully controlled atmospheric concentrations of the contaminant. The most important observations are the following:

(a) Adverse subjective responses have been reported [29,30] by test subjects exposed to concentrations exceeding 150 ppm. These include mild eye irritation by three of seven subjects exposed to 160 ppm for up to 83 minutes [29] and by one of five subjects exposed to 200 ppm for 7 hours, [30] and feeling of fatigue and sleepiness by all five or by three of five exposed to 200 ppm for 7 hours on the fourth and fifth consecutive days of exposure. [30]

(b) Exposure to 100 ppm for periods of 2-to 3-hours duration did not result in any decrease in psychophysiological performance. [91,92]

(c) Concentrations of approximately 100 ppm trichloroethylene interfered with psychophysiological performance after exposures of 8-hours duration; this was demonstrated by Salvini et al. [93]

(d) Quantitative evaluations of objective and subjective responses of human subjects exposed under controlled conditions to concentrations of less than 100 ppm trichloroethylene have not been reported.

In summary, deaths of several workers from exposure to trichloroethylene have been reported [36,90]; in the best documented case, exposure was at levels estimated to be between 1700 and 3300 ppm for ten minutes. Exposures at 1000 ppm for even short periods of time have resulted in effects on the central nervous system. Subjective complaints by one of 8 male volunteers was reported [91] at exposure levels of 300 ppm for two hours. No adverse effects were noted by psychophysiological testing of the same subjects at 100 ppm. In another paper, [92] results of psychophysiological testing of one subject for 2-1/2 hours indicated no significant effect on psychomotor performance from exposure at 100 ppm, but a slight effect was noted at 200 ppm. Adverse effects were reported by 3 of 7 subjects exposed at 160 ppm for less than 83 minutes. These effects, subjective in nature, included headache, drowsiness and mild eye irritation. [29]

Salvini et al [93] reported a statistically significant decrement in performance without clinical signs or symptoms at 90 to 130 ppm (average exposure level of 110 ppm). He concluded that 100 ppm was very close to the average concentration that would interfere with psychophysiological efficiency. This study included two groups of 6 males each, one of university students and the second of trichloroethylene workers. The same conclusions were drawn from the

results of each study group from which it is inferred that the threshold for psychophysiological effects is not affected by prolonged exposure. There is also evidence that prolonged exposure to trichloroethylene may result in dependency. It is significant that reports of liver damage from trichloroethylene are uncommon. Perhaps the suggestion [21] that liver damage is not caused by trichloroethylene except when it is contaminated by other compounds, especially tetrachloroethane, is the correct explanation.

As discussed above, the study by Salvini et al [93] indicates that exposures of approximately 100 ppm may interfere with the psychophysiological efficiency of the worker. Therefore, a TWA limit of 100 ppm will protect most of the workers but with probably very little margin of safety at this level of exposure.

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VII. APPENDIX I.

SAMPLING FOR TRICHLOROETHYLENE

Atmospheric Sampling

(a) General Requirements

(1) The measurement of air concentrations shall be within the worker's breathing zone and shall meet the following criteria in order to evaluate conformance with the standard:

(2) Samples collected shall be representative of the individual worker's exposure.

(3) Sampling data sheets shall include a log of:

(A) The date and time of sample collection.

(B) Sampling duration.

(C) Volumetric flowrate of sampling.

(D) A description of the sampling location.

(E) Other pertinent information.

(b) Breathing Zone Sampling

(1) Breathing zone samples shall be collected as near as practicable to the worker's face without interfering with his freedom of movement and shall characterize the exposure from each job or specific operation in each production area.

(2) A portable battery-operated personal sampling pump plus an activated charcoal tube shall be used to collect the sample.

(3) The activated charcoal tube shall be attached to the worker's clothing; the shirt collar is convenient for this purpose.

(4) The sampler shall be operated at a flowrate of one (1) liter per minute and samples shall be collected for a maximum of 10 minutes for ceiling values and a minimum of 10 minutes for time-weighted averages.

(5) Breathing zone samples shall be collected to permit calculation of a time-weighted average exposure for every operation involving exposure to trichloroethylene in sufficient numbers to express the variability of the work situation. The number of samples to be collected and analyzed, as a minimum, based on the number of workers exposed at any single type of operation or in any given work area is listed in Section 8 of this standard.

(6) An unused activated charcoal tube from the same batch shall be provided to the analytical laboratory to determine the blank correction which must be applied to the analytical results.

(c) Apparatus

(1) Pump, battery-operated, complete with clip for attachment to the worker's belt or a reliable, calibrated hand pump. All pumps and flowmeters must be calibrated using a calibrated wet test meter, or other reference, as described in (d)(5), below.

(2) Charcoal tubes: glass tube with both ends flame-sealed 7 cm long with a 6 mm O.D. and a 4 mm I.D., containing 2 sections of 20/40 mesh activated charcoal separated by a 2 mm portion of urethane foam. The absorbing section contains 100 mg of charcoal, the back-up section 50 mg. A 3 mm portion of urethane foam is placed between the

outlet end of the tube and the backup section. A plug of glass wool is placed in front of the absorbing section. The pressure drop across the tube must be less than one inch of mercury at a flowrate of 1 liter per minute.

(d) Calibration of Sampling Instruments

(1) Air sampling instruments shall be calibrated after making any repairs or modifications to the sampling system and at least once a year with a reference such as a wet test meter over a normal range of flowrates and pressure drops.

(2) The wet test meter shall be in good working condition and shall have been calibrated against a spirometer (or other primary standard) upon procurement, after each repair, and at least annually.

(3) Calibration curves shall be established for each sampling pump and shall be used in adjusting the pumps prior to field use.

(4) The volumetric flowrate through the sampling system shall be spot checked and the proper adjustments made before and during each study to assure obtaining accurate airflow data.

(5) Flowmeter Calibration Test Method

(A) Apparatus

- (i) Wet test meter or other reference
- (ii) Activated charcoal tube
- (iii) Pump with rotameter
- (iv) Rubber or vinyl tubing

- (v) Barometer
- (vi) Thermometer
- (vii) Stopwatch
- (viii) Small screwdriver
- (ix) Graph paper

(B) Procedure

(i) Level wet test meter. Check the water level which should just touch the calibration point at the left side of the meter. If water level is low, add water 1 to 2 F warmer than room temperature to fill point. Run the meter for 30 minutes before calibration.

(ii) Check the voltage of the pump battery with a voltmeter. A reading of 7.0 volts (for Mine Safety Appliances Company, Model G) is required for calibration. If reading is lower, charge batteries until a reading of 7.0 volts is obtained.

(iii) Break the tips of an activated charcoal tube to openings at least 2 mm in diameter at the ends.

(iv) Assemble the calibration train with the test meter, then the charcoal tube, and finally the pump in series.

(v) Turn the pump on, adjusting the rotameter with a screwdriver to a reading of 10 (read middle of the float).

(vi) Operate the system 10 minutes before starting the calibration.

(vii) The pointer on the meter should run clockwise and a pressure drop of not more than 1.0 inch of water indicated. If the pressure drop is greater than 1.0, disconnect and check the system.

(viii) Record the following on calibration data sheet: wet test meter reading, start and finish; elapsed time; pressure drop at manometer; air temperature; barometric pressure; and serial number of pump and rotameter.

(ix) Adjust the rotameter reading to 9.0, 8.0, and 7.0, respectively, and repeat step viii at each reading. Each point should run for 10 minutes or at least 0.5 cubic foot of air.

(x) Record the name of person performing the calibration, the date, serial number of the wet test meter, and the number of the pump and flowmeter system being calibrated.

(xi) Correct the wet test meter readings to standard conditions of pressure and temperature by means of the gas law equation.

(xii) Use graph paper to plot the actual airflow and the rotameter readings. Determine the rotameter reading that will result in a 1 liter/minute flowrate for the pump being calibrated.

VIII. APPENDIX II.

ANALYTICAL METHOD FOR TRICHLOROETHYLENE

(a) Principle of the Method

(1) A known volume of air is drawn through a charcoal tube to trap the organic vapors present.

(2) The charcoal in the tube is transferred to a small test tube and desorbed with carbon disulfide.

(3) An aliquot of the desorbed sample is injected into a gas chromatograph.

(4) The area of the resulting peak is determined and compared with areas obtained from the injection of standards.

(b) Range and Sensitivity

(1) The lower limit for trichloroethylene at a 16x1 attenuation on a gas chromatograph with a 10:1 splitter is 0.05 mg/sample. This value can be lowered by reducing the attenuation or by eliminating the 10:1 splitter.

(2) The upper limit value for trichloroethylene is 13.0 mg/sample. This value is the number of milligrams of trichloroethylene which the front section will hold before this compound is found on the backup section. The charcoal tube consists of two sections of activated charcoal separated by a section of urethane foam (see description of apparatus, Part VII). This upper value cannot be changed. If a particular atmosphere is suspected of containing a large amount of trichloroethylene, it is recommended that a smaller sampling volume be taken.

(c) Interferences

(1) When the amount of water in the air is so great that condensation actually occurs in the tube, organic vapors will not be trapped. Water vapor does not seem to be a problem, only water present as a mist.

(2) Any compound which has the same retention time as trichloroethylene at the operating conditions described in this method could be considered an interference. This type of interference can be overcome by changing the operating conditions of the instrument.

(d) Precision and Accuracy

(1) Precision of the analytical method: plus or minus 4.8%.

(2) Precision of the analytical method plus field sampling with the personal sampling pump has not been established.

(3) The accuracy of the sampling and analytical method, as established during breakthrough testing of the front section of activated charcoal: 91%.

(e) Advantages and Disadvantages of the Method

This method is advantageous in that it provides one basic method for determining many different organic solvents. The sampling device is small, portable, and involves no liquids. Interferences are minimal, and most of those which do occur can be eliminated by altering chromatographic conditions. The analysis of the tubes is accomplished using a quick instrumental method.

One disadvantage of the method is that the amount of sample which can be taken is limited by the weight of sample which the tube will hold before overloading. Also the precision of the method is limited by the reproducibility of the pressure drop across the tubes. Variability in this pressure drop will affect the flowrate, causing the volume to be imprecise since the pump is usually calibrated for one tube only.

(f) Apparatus consists of:

(1) An approved coal mine dust personal sampling pump for personal samples or any vacuum pump whose flow can accurately be determined at 1 liter per minute or less.

(2) Charcoal tubes: glass tube with both ends flame-sealed, 7 cm long with a 6 mm O.D. and a 4 mm I.D., containing 2 sections of 20/40 mesh activated charcoal separated by a 2 mm portion of urethane foam. The adsorbing section contains 100 mg of charcoal, the back-up section 50 mg. A 3 mm portion of urethane foam is placed between the outlet end of the tube and the backup section. A plug of glass wool is placed in front of the adsorbing section. The pressure drop across the tube must be less than one inch of mercury at a flowrate of 1 liter per minute.

(3) Gas chromatograph equipped with a flame ionization detector.

(4) Column (20 ft x 1/8 in) with 10% FFAP stationary phase on 80/100 mesh acid washed DMCS Chromosorb W solid support.

(5) A mechanical or electronic integrator or a recorder and some method for determining peak area.

(6) Small glass-stoppered test tubes or equivalent.

(7) Micro syringes: 10  $\mu$ l, and convenient sizes for making standards.

(g) Reagents

(1) Spectroquality carbon disulfide.

(2) Trichloroethylene, preferably chromatquality grade.

(3) Bureau of Mines Grade A helium.

(4) Prepurified hydrogen.

(5) Filtered compressed air.

(h) Procedure

(1) Cleaning of Equipment

All equipment used for the laboratory analysis should be washed in detergent followed by tap and distilled water rinses.

(2) Collection and Shipping of Samples

Both ends of the charcoal tube should be broken to provide openings of at least 2 mm which is one-half the I.D. of the tube. A smaller opening causes a limiting orifice effect which reduces the flow through the tube.

The smaller section of charcoal in the tube is used as a backup section and should therefore be placed nearest the sampling pump. Tubing may be used to connect the back of the tube to the pump, but no tubing must ever be put in front of the charcoal tube.

One liter per minute is the recommended sampling rate. A 10-liter sample is normally adequate. The tube must be supported in a vertical position for sampling. Due to the high resistance of the charcoal tube, this sampling method places a heavy load on the personal sampling pump. Therefore, it should not be assumed that this pump will run a full 8 hours without recharging the battery. After the sample is collected, the tube must be capped; caps are provided with commercial tubes.

One charcoal tube should be treated in the same manner as the sample tubes (break, seal, ship) with the exception that no air be drawn through it. This tube will serve as a blank.

If bulk samples are submitted in addition to charcoal tubes, the tubes should be shipped in a separate container from the bulk sample.

### (3) Analysis of Samples

#### (A) Preparation

Each charcoal tube is scored with a file and broken open in front of the first section of charcoal. The glass wool is removed and discarded. The charcoal in the first (larger) section is transferred to a small stoppered test tube. The separating section of foam is removed and discarded; the second section is transferred to another test tube. These two sections are analyzed separately.

#### (B) Desorption

Prior to analysis, 0.5 ml of carbon disulfide is pipetted into each test tube. (Caution: do not pipet by mouth.)

Tests indicate that desorption is complete in thirty minutes if the sample is agitated occasionally during this period.

EXTREME CAUTION MUST BE EXERCISED AT ALL TIMES WHEN USING CARBON DISULFIDE BECAUSE OF ITS HIGH TOXICITY AND FIRE AND EXPLOSION HAZARDS. IT CAN BE IGNITED BY HOT STEAM PIPES. ALL WORK WITH CARBON DISULFIDE MUST BE PERFORMED UNDER AN EXHAUST HOOD.

(C) Gas chromatographic conditions

Operating conditions for a typical gas chromatograph (Perkin-Elmer 900) are:

- (i) 85 cc/min. (70 psig) helium  
carrier gas flow
- (ii) 65 cc/min. (24 psig) hydrogen gas flow  
to detector
- (iii) 500 cc/min. (50 psig) airflow to detector
- (iv) 200 C injector temperature
- (v) 200 C manifold temperature (detector)
- (vi) Oven temperature 90 C isothermal
- (vii) Either dual column differential operation  
or the uncompensated mode may be used.

(D) Injection

The first step in the analysis is the injection of the sample into the gas chromatograph. To eliminate difficulties arising from blowback or distillation within the syringe needle, the solvent flush injection technique is employed. The 10  $\mu$ l syringe is first

flushed with solvent several times to wet the barrel and plunger. Three microliters of solvent are drawn into the syringe to increase the accuracy and reproducibility of the injected sample volume. The needle is removed from the solvent, and the plunger is pulled back about 0.2  $\mu$ l to separate the solvent flush from the sample with a pocket of air to be used as a marker. The needle is then immersed in the sample, and a 5  $\mu$ l aliquot is withdrawn, taking into consideration the volume of the needle, since the sample in the needle will be completely injected. After the needle is removed from the sample and prior to injection, the plunger is pulled back a short distance to minimize evaporation of the sample from the tip of the needle. Duplicate injections of each sample and standard should be made. No more than a 3% difference in area is to be expected.

#### (E) Measurement of area

The area of the sample peak is measured by an electronic integrator or some other suitable form of area measurement, and preliminary sample results are read from a standard curve prepared as discussed below.

#### (i) Calibration and Standards

##### (1) Preparation of Standards

It is convenient to prepare standards in terms of mg/0.5 ml of carbon disulfide because samples are desorbed in this amount of carbon disulfide. To minimize error due to the volatility of carbon disulfide, twenty times the weight can be injected into 10 ml of carbon disulfide. For example, to prepare a 0.3 mg/0.5 ml standard,

6.0 mg is injected into exactly 10 ml of carbon disulfide in a glass-stoppered flask. The density for trichloroethylene is used to convert 6.0 mg into microliters for easy measurements with a microliter syringe. A series of standards is prepared varying in concentration over the range of interest and analyzed under the same gas chromatographic conditions and during the same time period as the unknown samples. Curves are established by plotting concentration vs average peak area.

#### (2) Determination of Desorption Efficiency

It is necessary to determine the percentage of trichloroethylene on the charcoal that is removed in the desorption process. This desorption efficiency is determined once for a given compound, provided the same batch of charcoal is always used.

Activated charcoal, equivalent to the amount in the first section of the sampling tube (100 mg), is measured into a 2-in, 4-mm I.D. glass tube, flame-sealed at one end. The open end is capped. (The charcoal may be obtained from unused charcoal tubes.) A known volume of trichloroethylene is injected directly into the activated charcoal with a microliter syringe, and the tube is capped. The amount injected is usually equivalent to that present in a 10-liter sample at a concentration equal to the environmental standard.

A minimum of five tubes are prepared in this manner and allowed to stand for at least one day to assure complete adsorption of the trichloroethylene onto the charcoal. These tubes are desorbed and analyzed in exactly the same manner as sampling tubes. The results of

each analysis are compared to standards to determine what percentage of the original amount of trichloroethylene is desorbed. The average percentage is termed the desorption efficiency and is used as a factor in all sample analyses.

Experiments indicate that the desorption efficiency determined in this manner is essentially the same as that obtained by trapping a known amount of trichloroethylene vapor on the charcoal tube and analyzing. The first method is used because of its simplicity.

Because desorption efficiencies may vary from one laboratory to another and with different batches of charcoal, each laboratory should determine its own. However, for comparison, NIOSH determined a value of 97% for trichloroethylene, with one lot of activated charcoal.

(j) Calculations

(1) The first step in calculating the results is to read the weight in milligrams corresponding to each peak area from the standard curve. The standard curve is based on mg/0.5 ml of carbon disulfide, and therefore, no correction need be made for the volume of the sample injected, since this is identical to the volume of the standards injected.

(2) The weight of trichloroethylene in the front section of the blank tube is subtracted from the weight determined for the front section of each sample; a similar procedure is followed for the backup sections.

(3) Amounts present on the front and backup sections of the same tube are then added to calculate the total amount in the sample.

(4) This total weight of trichloroethylene in the tube is corrected by dividing by the desorption factor to determine the total number of milligrams in the sample.

(5) Milligrams are converted into parts per million by volume in the air sampled using the following equation:

$$\text{at 25 C} \quad \text{ppm} = \frac{24450 \text{ ml/mole} \times \text{mg/liter}}{\text{molecular wt}}$$

for a 10-liter air sample of trichloroethylene:

$$\text{ppm} = \frac{24450 \text{ ml/mole} \times \text{mg in sample/10 liters}}{131.40 \text{ g/mole}}$$

$$\text{ppm} = 18.61 \times \text{mg in sample}$$

IX. APPENDIX III.  
MATERIAL SAFETY DATA SHEET

The following items of information which are applicable to a specific product or material containing trichloroethylene shall be provided in the appropriate section of the Material Safety Data Sheet or approved form. If a specific item of information is (ie, flash point) initials "n.a." (not applicable) shall be inserted.

(a) The product designation in the upper left hand corner of both front and back to facilitate filing and retrieval. Print in upper case letters in as large a print as possible.

(b) Section I. Source and Nomenclature.

(1) The name, address, and telephone number of the manufacturer or supplier of the product.

(2) The trade name and synonyms for a mixture of chemicals, a basic structural material, or for a process material; and the trade name and synonyms, chemical name and synonyms, chemical family, and formula for a single chemical.

(c) Section II. Hazardous Ingredients

(1) Chemical or widely recognized common name of all hazardous ingredients.

(2) The approximate percentage by weight or volume (indicate basis) which each hazardous ingredient of the mixture bears to the whole mixture. This may be indicated as a range or maximum amount; ie, 10-20% V; 10% max. W.

(3) Basis for toxicity for each hazardous material such as established OSHA standard (TLV) in appropriate units and/or LD50 showing amount and mode of exposure and species, or LC50 showing concentration, duration of exposure, and species.

(d) Section III. Physical Data.

(1) Physical properties of the total product including boiling point and melting point in degrees Fahrenheit; vapor pressure, in millimeters of mercury, vapor density of gas or vapor (air=1); solubility in water, in parts per hundred parts of water by weight; specific gravity (water=1); volatility, indicate if by weight or volume, at 70 degrees or ether=1; and appearance and odor.

(e) Section IV. Fire and Explosion Hazard Data.

(1) Fire and explosion hazard data about a single chemical or a mixture of chemicals, including flash point, in degrees Fahrenheit; flammable limits, in percent by volume in air; suitable extinguishing media or agents; special fire fighting procedures; and unusual fire and explosion hazard information.

(f) Section V. Health Hazard Data.

(1) Toxic level for total compound or mixture, relevant symptoms of exposure, skin and eye irritation properties, principal routes of absorption, effects of chronic (long-term) exposure, and emergency and first aid procedures.

(g) Section VI. Reactivity Data.

(1) Chemical stability, incompatibility, hazardous decomposition products, and hazardous polymerization.

(h) Section VII. Spill or Leak Procedures.

(1) Detailed procedures to be followed with emphasis on precautions to be taken in cleaning up and safe disposal of materials leaked or spilled. This includes proper labeling and disposal of containers containing residues, contaminated absorbents, etc.

(i) Section VIII. Special Protection Information.

(1) Requirements for personal protective equipment, such as respirators, eye protection, protective clothing, and ventilation, such as local exhaust (at site of product use or application), general, or other special types.

(j) Section IX. Special Precautions.

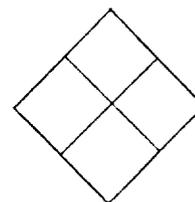
(1) Any other general precautionary information such as personal protective equipment for exposure to the thermal decomposition products listed in Section VI, and to particulates formed by abrading a dry coating, such as by a power sanding disc.

(k) The signature of the responsible person filling out the data sheet, his address, and the data on which it is filled out.

|                     |
|---------------------|
| PRODUCT DESIGNATION |
|---------------------|

**MATERIAL SAFETY  
DATA SHEET**

Form Approved  
Budget Bureau No.  
Approval Expires  
Form No. OSHA



| SECTION I SOURCE AND NOMENCLATURE               |                         |
|---|-------------------------|
| MANUFACTURER'S NAME                             | EMERGENCY TELEPHONE NO. |
| ADDRESS (Number, Street, City, State, ZIP Code) |                         |
| TRADE NAME AND SYNONYMS                         | CHEMICAL FAMILY         |
| CHEMICAL NAME AND SYNONYMS                      | FORMULA                 |

| SECTION II HAZARDOUS INGREDIENTS |  |                                 |          |         |          |       |
|----------------------------------|--|---------------------------------|----------|---------|----------|-------|
| BASIC MATERIAL                   | APPROXIMATE<br>OR MAXIMUM<br>% WT. OR VOL. | ESTABLISHED<br>OSHA<br>STANDARD | LD<br>50 |         | LC<br>50 |       |
|                                  |  |                                 | ORAL     | PERCUT. | SPECIES  | CONC. |
|                                  |  |                                 |          |         |          |       |
|                                  |  |                                 |          |         |          |       |
|                                  |  |                                 |          |         |          |       |
|                                  |  |                                 |          |         |          |       |
|                                  |  |                                 |          |         |          |       |
|                                  |  |                                 |          |         |          |       |
|                                  |  |                                 |          |         |          |       |
|                                  |  |                                 |          |         |          |       |
|                                  |  |                                 |          |         |          |       |

| SECTION III PHYSICAL DATA             |                              |                              |                                   |
|---------------------------------------|------------------------------|------------------------------|-----------------------------------|
| BOILING POINT                         | °F.                          | VAPOR PRESSURE               | mm Hg.                            |
| MELTING POINT                         | °F.                          | VAPOR DENSITY (Air=1)        |                                   |
| SPECIFIC GRAVITY (H <sub>2</sub> O=1) |                              | EVAPORATION RATE ( _____ =1) |                                   |
| SOLUBILITY IN WATER                   | Pts/100 pts H <sub>2</sub> O | VOLATILE                     | % Vol.                      % Wt. |
| APPEARANCE AND ODOR                   |                              |                              |                                   |

| SECTION IV FIRE AND EXPLOSION HAZARD DATA |                                    |       |
|---|------------------------------------|-------|
| FLASH POINT                               | FLAMMABLE<br>(EXPLOSIVE)<br>LIMITS | UPPER |
| METHOD USED                               |                                    | LOWER |
| EXTINGUISHING MEDIA                       |                                    |       |
| SPECIAL FIRE FIGHTING PROCEDURES          |                                    |       |
| UNUSUAL FIRE AND EXPLOSION HAZARDS        |                                    |       |

PRODUCT DESIGNATION

SECTION V HEALTH HAZARD DATA

TOXIC LEVEL

CARCINOGENIC

PRINCIPAL ROUTES OF ABSORPTION

SKIN AND EYE IRRITATION

RELEVANT SYMPTOMS OF EXPOSURE

EFFECTS OF CHRONIC EXPOSURE

EMERGENCY AND FIRST AID PROCEDURES

SECTION VI REACTIVITY DATA

CONDITIONS CONTRIBUTING TO INSTABILITY

CONDITIONS CONTRIBUTING TO HAZARDOUS POLYMERIZATION

INCOMPATIBILITY (Materials to Avoid)

HAZARDOUS DECOMPOSITION PRODUCTS

SECTION VII SPILL OR LEAK PROCEDURES

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED

WASTE DISPOSAL METHOD

SECTION VIII SPECIAL PROTECTION INFORMATION

VENTILATION REQUIREMENTS LOCAL EXHAUST

PROTECTIVE EQUIPMENT (Specify Types) EYE

MECHANICAL (General)

GLOVES

SPECIAL

RESPIRATOR

OTHER PROTECTIVE EQUIPMENT

SECTION IX SPECIAL PRECAUTIONS

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORAGE

OTHER PRECAUTIONS

Signature

Address

Date

TABLE X-1

COMMON, BRAND- AND TRADE NAMES FOR TRICHLOROETHYLENE\*

|                       |                 |
|-----------------------|-----------------|
| Acetylene Trichloride | TRI             |
| Algylen               | Triad           |
| Blacosolv             | Trial           |
| Chlorylen             | Triasol         |
| Circosolv             | Trichloran      |
| Dow-Tri               | Trichloren      |
| Ethynyl Trichloride   | Trichloroethene |
| Fleck-Flip            | Triclene        |
| Gemalgene             | Tri-Clene       |
| Lanadin               | Trielene        |
| Lethurin              | Trielin         |
| Nialk                 | Trilene         |
| Perm-A-Clor           | Triline         |
| Petzinol              | Trimar          |
| Philex                | Vestrol         |
| TCE                   | Vitran          |
| Threthylen            | Westrosol       |
| Trethylene            |                 |

\*From Stecher, [3] and National Safety Council. [4]

TABLE X-2

## PROPERTIES OF TRICHLOROETHYLENE

|                      |   |  |
|----------------------|---|--|
| Molecular Formula    | - | $C_1CH=CCl_2$  |
| Formula Weight       | - | 131.40   |
| Boiling Point        | - | 87.1 C at 760 mm Hg  |
| Melting Point        | - | -73 C  |
| Liquid Density       | - | 1.465 g/ml at $\frac{20\text{ C}}{4\text{ C}}$   |
| Solubility           | - | 0.1 part per 100 parts of water at 25 C; mixes freely with alcohols, ethers; and many other organic solvents.      |
| Flash Point          | - | None by standard methods   |
| Ignition Temperature | - | 463 C  |
| Vapor Pressure       | - | 100.0 mm mercury at 31.5 C<br>74.3 mm mercury at 25.0 C<br>10.0 mm mercury at -11.8 C<br>1.0 mm mercury at -42.9 C |
| Vapor Density        | - | 4.5 (air = 1.0)  |
| Odor Threshold       | - | 21.4 ppm [8]   |
| Conversions          | - | 1 ppm = 5.38 mg/m <sup>3</sup> @25 C<br>1 mg/liter = 186.1 ppm   |

TABLE X-3

TRICHLOROETHYLENE EXPOSURES IN  
SWEDISH ENGINEERING WORKSHOPS\*

| Job Location                       | Minutes** | Trichloroethylene (ppm) |      |
|------------------------------------|-----------|-------------------------|------|
|                                    |           | Range                   | Mean |
| Open Air                           | 2.5       | 0-0                     | 0    |
| Less than 5 meters<br>from tank    | 4.8       | 0-140                   | 23   |
| Greater than 5<br>meters from tank | 4.5       | 0-80                    | 7    |
| Sorting, before<br>degreasing      | 2.7       | 0-375                   | 32   |
| Degreasing                         | 4.7       | 0-400                   | 50   |
| Sorting, after<br>degreasing       | 2.4       | 0-375                   | 46   |
| Cleansing                          | 4.8       | 10-375                  | 225  |
| Inspection of tank                 | 4.7       | 0-375                   | 70   |
| Refilling                          | 4.8       | 10-415                  | 36   |

\*Ahlmarm et al [111]

\*\*Mean time spent by each operator at the various locations.  
It is understood that an operator may perform at a given  
location with greater frequency than another operator.

TABLE X-4

ENVIRONMENTAL HEALTH STANDARDS FOR TRICHLOROETHYLENE  
PROMULGATED BY VARIOUS COUNTRIES

| Country                 | Acceptable Concentration |         |
|-------------------------|--------------------------|---------|
|                         | ppm                      | mg/cu m |
| Bulgaria                | (10)                     | 50      |
| Czechoslovakia          | 46                       | 250     |
| Finland                 | 100                      | 525     |
| Germany                 | 100                      | 535     |
| Hungary                 | (10)                     | 50      |
| Japan                   | 100                      | 520     |
| Poland                  | (10)                     | 50      |
| Rumania                 | (10)                     | 50      |
| United Arab<br>Republic | 200                      | (1075)  |
| U.S.S.R.                | (2)                      | 10      |
| Yugoslavia              | 100                      | 520     |

Values in parentheses are approximate conversions where the standard was published in only one of the two units listed above.

From [118]